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Global Adoption of Agricultural Biotechnology: Modeling and Preliminary Results

Jorge Fernandez-Cornejo, Ruben Lubowski, and Agapi Somwaru *

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* Authors are economists at the Economic Research Service, U.S. Department of Agriculture, 1800 M Street, NW, Washington DC, 20036. Please do not cite, reproduce, or distribute without permission of the authors. The views expressed are those of the authors and do not necessarily correspond to the views or policies of the Economic Research Service or the U.S. Department of Agriculture.

Introduction

This paper analyzes the economic and land-use implications of world trends in the adoption of agricultural biotechnology. Driven by farmers' expectations of higher yields, savings in management time, and lower pesticide costs, the global adoption of biotech corn, soybeans, and cotton crop varieties has increased rapidly over the past ten years. An estimated 220 million acres of biotech crops with herbicide tolerance and/or insect resistance traits were cultivated in 21 countries worldwide in 2005, a 10-percent increase over 2004. At present, only a few countries account for most of the world's biotech acreage (Figure 1). U.S. acreage accounts for about 55 percent, followed by Argentina (19 percent), Brazil (10 percent), Canada (6 percent), China (4 percent), Paraguay (2 percent), and India (more than 1 percent).

Technological change has been acknowledged as a critical component of productivity and economic growth (Solow, 1994; Griliches, 1995). The rapid adoption and diffusion of new technologies within the U.S. agricultural sector has resulted in sustained agricultural productivity growth and ensured an abundance of food (Huffman and Evenson, 1993; Alston and Pardey, 1996; Ball et al., 1997). However, since technological change can also affect employment, trade, real wages, and the environment, the adoption of new technologies may trigger asymmetric effects on different sectors of the economy.

Over the past decade, developments in modern biotechnology have expanded the scope of biological innovations by providing new tools for increasing crop yields and agricultural productivity while causing some environmental and consumer concerns, particularly in Europe. Agricultural biotechnology is a collection of scientific techniques, including genetic engineering, that are used to create, improve, or modify plants, animals, and microorganisms. Genetic engineering modifies organisms by recombinant DNA techniques. These techniques allow a more precise and time-saving alteration of a plants' traits, facilitating the development of characteristics that are not feasible through traditional plant breeding. Genetic engineering also allows scientists to target a single plant trait, thus decreasing the number of unintended characteristics that often accompany traditional breeding techniques, and increasing the speed at which breeders can develop new varieties. The first generation of genetically engineered (GE) crops includes crops with pest management traits, including those carrying genes selected for resistance to certain insects and/or tolerance to specific herbicides.

GE varieties of soybeans, corn, and cotton have been available commercially since 1996, and the rate of adoption by farmers has climbed in most years since then. For the most part, farmers have adopted herbicide-tolerant (HT) varieties—which help control weeds by surviving certain potent herbicides that previously would have destroyed the crop along with the targeted weeds—and insect-resistant (Bt) varieties, which contain a gene from the soil bacterium, *Bacillus thuringiensis* (Bt) that produces a protein toxic to specific insects (European corn borer and corn rootworm for the case of corn and tobacco budworm, bollworm, and pink bollworm for the case of cotton). The main crop adopted is soybeans as HT soybeans reached 134 million acres in 2005 (ISAAA, 2006) followed by GE corn (HT and Bt) with 52 million acres, and cotton (HT and Bt) that reached 24 million acres. Other GE crops planted by U.S. farmers over the past 10 years include HT canola, virus-resistant papaya, and virus-resistant squash. In addition, Bt potato varieties were introduced in 1996 but withdrawn from the market after the 2001 season, and a tomato variety genetically engineered to remain on the vine longer and ripen to full flavor after harvest was introduced in 1994 but was withdrawn from the market after being available sporadically for several years (Fernandez-Cornejo and Caswell, 2006).

The overall objectives of the study are to examine some of the global economic and environmental implications of increasing adoption of major GE crop varieties within the countries that are currently the leading adopters as well as in others. We explore effects of different adoption scenarios for agricultural biotechnology and consider implications for production, trade, prices, as well as the location and characteristics of land in agricultural production. This study provides the first examination of these issues in an integrated economic and biophysical framework. We focus on the adoption of two major crops: HT soybeans and Bt corn.

The rest of this paper will briefly describe the model used, discuss recent changes introduced to the model, and present preliminary simulation results on the global economic effects of increased GE crop adoption under several scenarios.

The Model and Data

To examine these issues, we updated and refined the Future Agricultural Resources Model (FARM), which was developed by the Economic Research Service (ERS) of the U.S. Department of Agriculture. FARM II is an integrated modeling framework designed to analyze global changes related to long-run agricultural and environmental resources. This model was originally developed by Roy Darwin and others (John Sullivan, Kevin Ingram, Vince Breneman from ERS, Lahouari Bounoua, from NASA and the University of Maryland and Marc Imhoff from NASA) (Darwin et al, 1995, Darwin and Kennedy, 2002). Darwin and his collaborators were some of the first to introduce into their global economic modeling the concept of agro-ecological zones (AEZ), where land is divided into classes based on climate and other physical characteristics that affect the suitability of land to grow different crops and productivity of different uses.

Previous versions of FARM have been used primarily to analyze the impacts of greenhouse gas emissions on agriculture (Darwin et al., 1994, 1995; Darwin, 1999, 2003, 2004b; Darwin and Kennedy, 2000). Other applications include: costs of sea level rise (Darwin and Tol, 2001); the impacts of changes in agricultural technology on land use (Ianchovichina et al., 2001); the costs of protecting global ecosystem diversity (Lewandrowski et al., 1999); and the effects of trade deregulation and population growth on tropical forests (Darwin et al., 1996).

The FARM framework can be visualized in terms of an environmental and economic component (Darwin et al., 1995). The environmental component consists of a geographic information system that links land cover and climate data with land and water resources (Figure 2). Climate is linked with land resources by agro-ecological zones defined primarily in terms of growing season. Growing season is the period during a year that soil temperature and moisture conditions support plant growth. Climate is linked with water resources through surface and subsurface runoff—the amount of precipitation that is not evapotranspirated back into the atmosphere. Evapotranspiration is the combined loss of water from a given area in a specific time by evaporation from the soil surface and by transpiration from plants.

The current version of FARM's underlying database reflects a number of major updates. FARM II includes a new land and water resources database linked with production of agricultural and forestry commodities by enhanced agro-ecological zones (AEZs). First, the data where possible are calibrated to 1997, rather than 1990, values. Second, the land-cover characteristics are organized by country and 0.5° lat.-long. grid, rather than 12 aggregate regions and 0.5° lat.-long. grid. Third, because the initial resolution of the land-cover characteristics data is 1.0 km^2, each country-grid combination may have multiple land-cover characteristics, rather than just one. Fourth, agro-ecological zones, which were initially called land classes, are derived from actual contemporary monthly temperature and precipitation data, rather than from monthly values averaged over the 1930-1960 period. Finally, data on U.S. agricultural water withdrawals are organized by U.S. State, rather than for the U.S. as a whole.

The associated data linking these land and water resources with production also reflect a number of major updates and revisions. The database has recently been updated using 1997 data and enhanced agro-ecological zones (AEZs), country-level production with 173 crops, 37 livestock products, 6 timber commodities. While production was previously determined by growing season, the current version uses plant hardiness zones (PHZ) (9 categories) and thermal regimes (six categories) in addition to length of growing season (six categories) in order to distribute commodities to land covers. Finally, distribution of livestock and forestry products is further constrained by population density.

FARM's economic component consists of a global computable general equilibrium (CGE) model (Figure 3). The CGE used for this analysis is a multi-sector, general equilibrium model of the global economy implemented in the General Algebraic Modeling System (GAMS). Both the static and dynamic versions of this model have been previously described and applied to diverse issues relating to trade liberalization (Roe, Somwaru and Diao, 2006, Diao, Roe and Somwaru 2002; Diao, Somwaru and Roe 2001; Diao and Somwaru 2000). FARM II, as a CGE modeling framework, accounts for all production and expenditures within each of its country/regions. A representative household in each region supplies primary factors to producers and maximizes utility with respect to household consumption, government consumption, and saving. Representative producers in each sector maximize profits associated with the utilization of the four primary factors—land, water, labor, and capital. Unlike other global models, FARM II explicitly models production systems including land by AEZ. Assuming constant returns to scale, capital and labor are freely mobile among national sectors while land and water endowments are fixed by agro-ecological zones. For simplicity, no independent government savings or borrowing is assumed, with the government spending all its tax revenues on consumption or household transfers. Investment is assumed to exactly equal depreciation so the capital stock remains constant.

FARM II incorporates the latest version of the Global Trade Analysis Project (GTAP) database, version 6, which represents the world economy as of 2001 (Dimaranan 2006). The CGE model is calibrated using the GTAP database but modified so that national production data is distributed proportionally as per FARM's environmental database, by land use and AEZ. Table 1 summarizes the sectors and country/regions used in this study. For this application, the data were aggregated into 17 sectors, including 8 agricultural commodities (seven crops—paddy rice, wheat, other grains, oilseeds, sugar, cotton, other crops—and livestock). In addition, we included nine other commodities: forestry, fish/meat/dairy, other processed foods, oil and gas, other minerals, textiles and apparel, manufacturing (non-metallic), other manufacturing, and services. The data were also aggregated into 19 countries/regions: Canada, United States, Mexico, Argentina, Brazil, Paraguay, other Western hemisphere, European Union (EU25), Russia (and other countries of the former Soviet Union), China, India, Pakistan, Indonesia, other East Asia, other South Asia, rest of Asia, Oceania, Africa, and the rest of the world (ROW).

Costs and Pecuniary Benefits of Agricultural Biotechnology Adoption

As a benchmark for modeling the impacts of adopting agricultural biotechnology, we restrict attention to production effects, assuming no differences in demand for GE varieties. In particular, we develop estimates of adoption potential and yield and cost effects (if any) from the adoption of Bt corn and HT soybeans across countries. We included only countries with at least 1 million hectares planted of the crop, with the exception of South Africa in the case of soybeans (Table 2).

The estimated potential adoption from current levels is based on estimated infestation at treatable levels (Table 3). It is expressed as percent of planted area and adapted from James (2003), unless otherwise indicated. The estimated adoption potentials for Bt corn range from a low of 20 percent in Ukraine to 60 percent in Brazil, India, Mexico, South Africa, and Other Africa. Potentials equal 40 percent in Argentina, Canada, China, European Union, United States, and other countries. [1] Estimated adoption potentials for HT soybeans are estimated at 90 percent for all the countries included.

[1] EU countries included here are: Austria, Belgium, Luxemburg, Czech Republic, France, Germany, Greece, Hungary, Italy, Netherlands, Poland, Portugal, Slovakia, Slovenia, and Spain.

Yield gains and costs are obtained from the compilation made by Brookes and Barfoot (2005) unless otherwise indicated. The yield gain estimates for Bt corn in the European Union (EU) are based on data for France, Italy, and Hungary. Yield gains for African countries are based on data for Nigeria, Ethiopia, Kenya, Tanzania, Congo, Mozambique, Zimbabwe, Malawi. Yield gains are estimated at either 5 or 10 percent for all countries included, with the exception of the Philippines where the estimated gains reach 25 percent.

Costs savings as well as technology costs were also estimated (Table 3). All costs are in US$. When sources reported costs in foreign currency, values were converted at the 2004 average exchange rate. Cost of the Bt corn technology for countries with missing data (Brazil, China, India, Romania, Ukrania, South Africa) are assumed equal to that of the U.S. and Argentina ($22/ha). The costs of the Bt corn technology for Philippines in Brookes and Barfoot appear to be too high ($50/ha) so we used the U.S. cost instead. Cost of the Bt corn technology for EU countries was assumed equal to that of Spain (the only EU country currently adopting). Cost savings of Bt corn for countries with missing data are assumed to be equal to those of the U.S. for temperate climates ($15.5/ha) or the Philippines for tropical climates ($14.3/ha).

For the case of the HT soybean technology, cost savings net of technology costs are the only source of benefits, with yield gains estimated at zero, following consensus estimates (Brookes and Barfoot, 2005). The costs of the HT soybean technology for countries with missing data are assumed to be equal to that of the U.S. (EU) or Argentina (China, India) and range widely from $4 to $35 per hectare. Cost savings of HT soybean for countries with missing data are assumed to be equal to those of Argentina (Paraguay, China) or South Africa (India). Cost savings of HT soybean for the U.S. was obtained from Sankula and Blumenthal (2004). Estimated cost savings, excluding technology costs, range from 27 $/Ha in Argentina to 88 $/Ha in Brazil.

Scenario Analysis of Biotechnology Adoption

Given these estimated pecuniary benefits and costs from adopting Bt corn and HT soybeans, in this preliminary analysis we consider five hypothetical cases for widening international adoption of these technologies. As described in Table 4, Scenarios 1 to 4 entail progressively greater numbers of countries and regions being assumed to adopt one or both biotech varieties, if relevant. Adoption for a particular country or region involves full adoption at the estimated potential with the associated yield and cost effects (if any) for each crop. Because the GTAP database does not separately identify corn and soybeans from other grains and oilseeds, respectively, effects are allocated to these broader categories according to each crop's respective share of the aggregate product.

Scenario 1 includes adoption in North America (U.S. and Canada) only; scenario 2 includes adoption in the entire Western Hemisphere (U.S., Canada, Mexico, Argentina, Brazil, Paraguay); scenario 3 includes adoption in the entire Western Hemisphere plus Asia (China, India, Indonesia, Philippines); scenario 4 considers global adoption of biotech corn and soybeans.

Scenario 5 considers an alternative characterization of the economic effects of biotechnology adoption. In scenarios 1-4, GE crops are assumed to entail the same yield and cost effects across all land types within a country. In reality, impacts on yields and cost savings could vary with the productivity of land and associated climate. Scenario 5 considers an increase in land productivity that is limited to land in temperate regions with an average growing season ranging from 61 to120 days, as shown in Figure 3. This productivity gain benefits all crop production activities and, by assumption, leads to average yield gains of about 5 percent. This scenario illustrates the possible effects of differentiated impacts by agro-ecological zone by simulating a hypothetical technology or set of technologies that would broadly increase the productivity of land in a particular zone which is currently one of the most productive for corn and soybeans.

Preliminary Results

Preliminary results from the simulations are summarized in Tables 5-8. All impacts are measured as percentage changes from the model baseline (according to the latest GTAP database, which represents the world economy as of 2001). Overall global effects are presented in Table 5. Estimated impacts generally increase progressively as a broader set of countries is assumed to adopt. In scenarios 1 to 4, greater worldwide adoption of Bt Corn and HT soybeans leads to moderate (0.2-1.5 %) increases in the aggregate production of agricultural commodities with an associated decline in prices of about 1.1 to 3% (Table 5). Global adoption leads to greater volume of world trade (an estimated increase of 3.3%) and lesser increases in trade value (about 1.2%) given the decline in prices. Price declines overshadow trade increases in scenario 3 where adoption occurs in the Western Hemisphere and Asia, leading to a small (0.17%) decline in trade value.

Results from scenario 5 differ in several key respects. Aggregate production increases and associated price declines are greater, given a different pattern of production increases. Nevertheless, the increase in trade volumes is smaller as increases in productivity are spread worldwide across a broader set of commodities, reducing the advantages from agricultural trade. The larger decline in prices combined with the smaller increase in trade volume produces an overall decline in the value of world trade relative to the baseline, compared to the increase with scenario 4. This illustrates the differential effects of productivity gains depending on the spatial distribution of simulated effects.

Tables 6-8 summarize the estimated global impacts on the production, prices, and volume of trade for the main agricultural commodities in the model. The estimated effects are similar for both oilseeds (e.g. soybeans) and other grains (e.g. corn) when adoption is restricted to the Western Hemisphere (scenarios 1 and 2) but increase by a greater amount for oilseeds when adoption spreads to Asia and the entire world (scenarios 3 and 4). The estimated increase in the production of oilseeds ranges from 0.13% with adoption only in U.S. and Canada to 2.5% under global adoption (Table 6).

Estimated production of other grains rises by 0.11% with adoption only in U.S. and Canada to 0.88% under global adoption. Price impacts, however, are consistently greater for other grains versus soybeans, with declines reaching 4.69% versus 3.86% under the global adoption case (Table 7). Under global adoption, the greatest predicted growth of production of other grains occurs in South Asia (India, Pakistan). These regions also experience the largest increases in oilseed production, along with EU, Africa, and Mexico.

Impacts on the production (Table 6) and prices (Table 7) of other major agricultural commodities are also generally positive with production of paddy rice declining somewhat (0.73 percent) in the global adoption scenario due to shifts in land (chiefly in Other East Asia) and changes in consumption. Production of other major agricultural products is estimated to increase, with gains ranging from 0.27% for wheat, 0.90% for other crops, and 1.25% for livestock under the global case. Possible explanations for these effects are changes in comparative advantage, increases in demand due to falling consumer prices, and availability of cheaper feed in the case of livestock.

Increasing worldwide adoption of GE corn and soybeans leads to greater volume of trade in agricultural products across most commodities and scenarios (Table 8). As adoption grows beyond the Western Hemisphere, however, the growth in trade volumes is smaller, and the volume of trade in oilseeds actually declines by 1.5% in the global adoption case. This compares with an increase in oilseed trade volume of more than 2 percent when only the Western Hemisphere adopts (scenario 2). This could be expected as comparative advantage in production appears to erode with broader technological adoption, reducing the benefits of trade. Similarly, the volume of trade in other grains rises by 3.9% when only the Western Hemisphere adopts and rises by just 1.5% in the global adoption scenario. Other commodities experience steadier increases in trade volumes as adoption becomes widespread, as countries increase imports to compensate for land and other resources diverted to the production of corn and soybeans.

For other grains and oilseeds, production and price effects are larger under scenario 5 than scenario 4, while results for other commodities are mixed. This can be explained by the broader set of commodities, including soybeans, to which productivity impacts accrue as well as to the restriction of productivity gains to a single AEZ with a comparative advantage for these crops in certain countries/regions. Impacts on trade volumes are more negative for oilseeds and more positive for other grains in scenario 5 versus 4, perhaps indicating broader production of soybeans and more specialized production of corn. Results for trade volumes of other commodities show no consistent pattern. This experiment illustrates the sensitivity of results to the spatial location and characterization of the simulated technological benefits.

To further explore these issues, some additional simulations were conducted. If the land productivity increase is restricted to only other grains, as opposed to all crops, an increase of just 2 percent in the productivity of the same temperate zone AEZ produces equivalent overall production increases in other grains as in the global adoption scenario. This indicates that more geographically limited changes in productivity could produce greater production impacts compared to broader adoption of improved technology.

Conclusion

This paper describes a unique global general equilibrium framework for integrated economic and environmental modeling of the impacts of global biotechnology adoption. We simulate a variety of scenarios that explore effects from progressively broader sets of nations and regions adopting two key agricultural biotechnologies, Bt corn and HT soybeans, and associated yield and cost effects (if any). These scenarios focus on changes in the production technology and assume no change in associated demand relationships. Preliminary results indicate moderate increases in production of these and other commodities, and corresponding declines in prices. Trade volumes and values also increase generally but peak with less than global adoption levels.

This initial application of the model focused on the economic consequences. Consideration of the impacts on land and water resources was limited to a scenario exploring an alternative characterization of biotechnology impacts restricted to one particular agro-ecological zone (AEZ). Next steps in the analysis will involve additional disaggregation of results by country and AEZ, including an examination of land and water use tradeoffs. Further research will also involve sensitivity analysis of different adoption scenarios and inclusion of data on BT cotton and other GE crops.

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Table 1. Model Regions and Sectors

Countries/Regions (19):		Commodities/Activities (17):	
SSA	Africa	pfb	Cotton
ARG	Argentina	osd	Oilseeds
BRA	Brazil	ocr	Other Crops
CAN	Canada	gro	Other Grains
CHN	China	pdr	Rice
E_U	EU25	c_b	Sugar, Cane and Beets
IND	India	wht	Wheat
IDN	Indonesia	lvk	Livestock
MEX	Mexico	fmm	Fish, Meat, Dairy
ROW	Middle East	opf	Other Processed Food
OCE	Oceania	frs	Forest
OEA	Other East Asia	nmm	Manufacturing, Non-Metallic
OSA	Other South Asia	omn	Manufacturing, Other
OWH	Other Western Hemisphere	cog	Oil and Gas
PAK	Pakistan	min	Other Minerals
PRY	Paraguay	srv	Services
XOA	Rest of Asia	tcf	Textile and Apparel
RUS	Russia		
USA	United States		

Table 2. Total Planted Acreage of All Corn and Soybeans, by Select Countries, 2003-2004

Country	Corn	Soybeans
	Million Hectares	
Argentina	2.1	14.0
Brazil	12.4	21.5
Canada	1.2	1.0
China	24.1	9.3
EU	6	
India	7	6.5
Indonesia	3.2	
Mexico	7.7	
Other Africa	22.9	
Paraguay		1.8
Philippines	2.5	
Romania	2.6	
South Africa	3.3	0.1
Ukraine	2	
United States	28.8	29.3
Rest of World	14.6	4.8
World Total	140.4	88.3

Sources: U.S. Department of Agriculture, NASS Agricultural Statistics (2005) and FAO.

Table 3. Estimated Global Adoption Potential, Benefits, and Costs for GE Crops: Corn and Soybeans

Country	Bt Corn				HT Soybeans			
	Estimated Potential Adoption	Yield Gain	Cost Savings, Excluding Technology Costs	Technology Costs	Estimated Potential Adoption	Yield Gain	Cost Savings, Excluding Technology Costs	Technology Costs
	%	%	$/Ha	$/Ha	%	%	$/Ha	$/Ha
Argentina	40	10	0	22	90	0	27	4
Brazil	60	10	15.5	22	90	0	88	15
Canada	40	5	15.5	22	90	0	52	35
China	40	5	15.5	22	90	0	27	4
EU	40	5	15.5	23				
India	60	10	14.3	22	90	0	36	4
Indonesia	40	10	14.3	22				
Mexico	60	10	14.3	22				
Other Africa	60	10	14.3	22				
Paraguay					90	0	27	4
Philippines	40	25	14.3	22				
Romania	40	5	15.5	22				
South Africa	60	5	14.3	22	90	0	36	26.3
Ukraine	20	5	15.5	22				
United States	40	5	15.5	22	90	0	67	17.3

Sources: Estimates derived for this study based on Brookes and Barfoot (2005), Sankula and Blumenthal (2004), and James (2003).

Table 4. Scenario Description

Scenario	Description	Comments
Scenario 1	US and Canada adopt	Adoption at full estimated potential.[1]
Scenario 2	All Western Hemisphere adopts	Adoption at full estimated potential.
Scenario 3	Western Hemisphere and Asia adopt	Adoption at full estimated potential.
Scenario 4	Global adoption	Adoption at full estimated potential.
Scenario 5	Biotechnology adoption modeled as productivity increase by agro-ecological zone (AEZ).	Productivity increase equal to Bt corn yield gain in areas with average growing season of 61-120 days and none elsewhere.

[1] Full estimated adoption potential is the percent of planted acreage by crop shown in Table 3. All adoption scenarios include estimated yield and cost effects for corn and cost effects for soybeans as shown in Table 3.

Table 5. Aggregate Impacts of Biotechnology Adoption Scenarios

Variable	Scenario 1 U.S. and Canada	Scenario 2 Western. Hemisphere	Scenario 3 Western Hem. & Asia	Scenario 4 Global adoption	Scenario 5 Productivity increase where growing season is 61-120 days
			Percentage difference from the baseline		
World Agricultural Prices	-0.991	-1.526	-1.110	-1.972	-5.044
World Agricultural Production	0.230	0.380	0.440	0.619	2.218
World trade (value)	0.090	0.160	-0.170	1.170	-3.709
World trade (volume)	1.107	1.695	1.196	3.310	1.705

[1] Scenarios 1-4 are for the adoption Bt corn and HT soybeans with yield and cost effects and cost effects only, respectively. Scenario 5 is an alternate scenario in which productivity for only one AEZ is increased (see Table 4).

Table 6. Estimated Changes in Global Agricultural Production of Main Commodities Due to Biotechnology Adoption Scenarios [1]

Commodity	Scenario 1 U.S. and Canada	Scenario 2 Western. Hemisphere	Scenario 3 Western Hem. & Asia	Scenario 4 Global adoption	Scenario 5 Productivity increase where growing season is 61-120 days
			Percentage difference from the baseline		
Oilseeds	0.130	0.190	0.890	2.520	4.170
Other crops	0.290	0.479	0.609	0.899	0.030
Other grains	0.110	0.380	0.490	0.880	2.010
Paddy rice	-0.090	-0.210	0.270	-0.730	2.879
Wheat	-0.060	0.030	0.260	0.270	1.589
Livestock	0.349	0.598	0.668	1.266	0.027

[1] Scenarios 1-4 are for the adoption Bt corn and HT soybeans with yield and cost effects and cost effects only, respectively. Scenario 5 is an alternate scenario in which productivity for only one AEZ is increased (see Table 4).

Table 7. Estimated Changes in Global Agricultural Prices of Main Commodities Due to Biotechnology Adoption Scenarios [1]

Commodity	Scenario 1 U.S. and Canada	Scenario 2 Western. Hemisphere	Scenario 3 Western Hem. & Asia	Scenario 4 Global adoption	Scenario 5 Productivity increase where growing season is 61-120 days
			Percentage difference from the baseline		
Oilseeds	-1.536	-2.741	-2.068	-3.865	-7.068
Wheat	-1.305	-2.782	2.507	0.645	-3.262
Other grains	-2.488	-3.741	-3.099	-4.694	-6.911
Paddy rice	1.057	0.205	-1.540	-4.424	-11.906
Other crops	-2.136	-3.009	-2.808	-3.671	-0.093
Livestock	-1.095	-1.788	-1.416	-1.848	-0.068

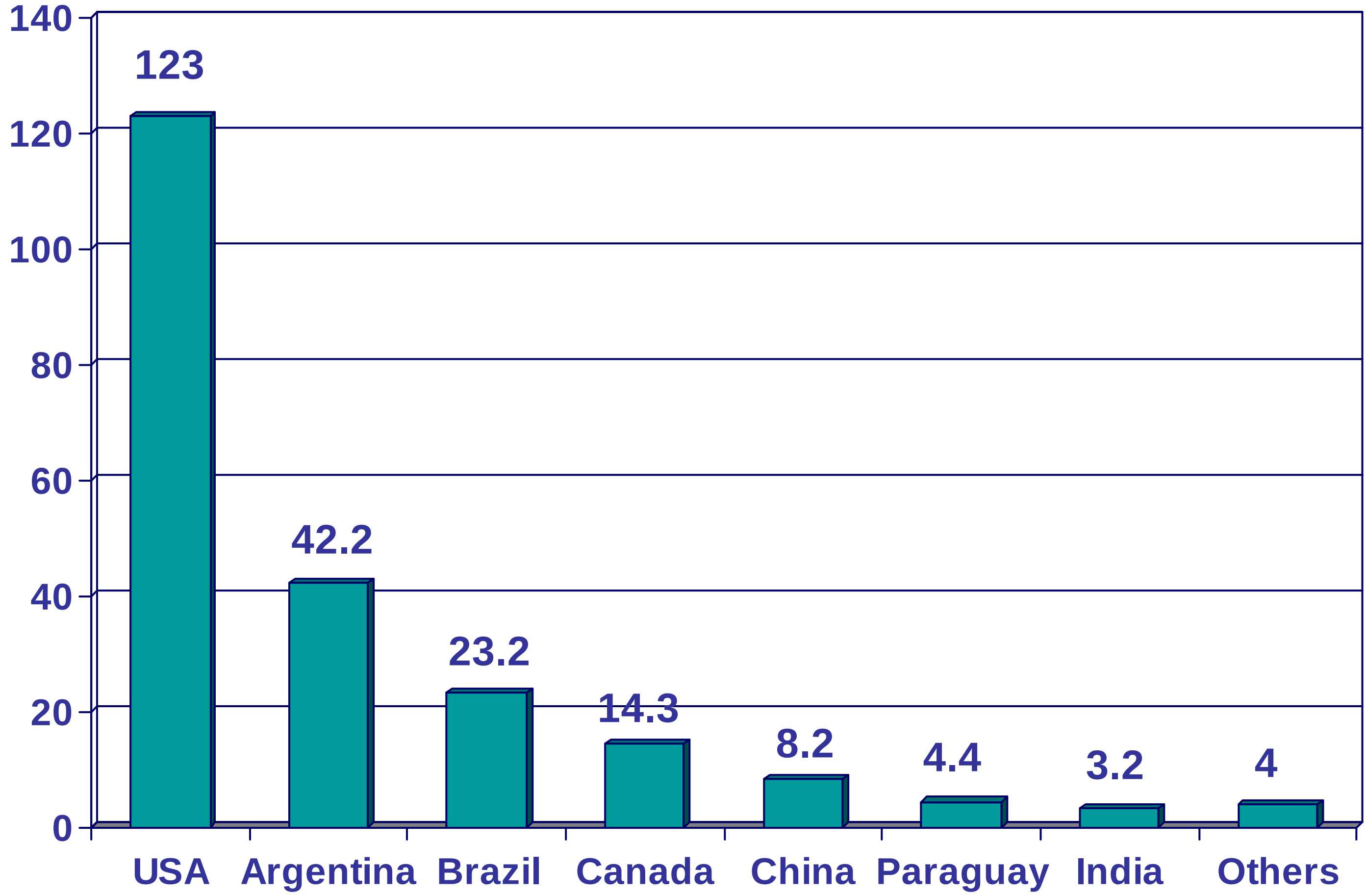
[1] Scenarios 1-4 are for the adoption Bt corn and HT soybeans with yield and cost effects and cost effects only, respectively. Scenario 5 is an alternate scenario in which productivity for only one AEZ is increased (see Table 4).

Table 8. Estimated Changes in Volume of Agricultural Trade in Main Commodities Due to Biotechnology Adoption Scenarios [1]

Commodity	Scenario 1 U.S. and Canada	Scenario 2 Western. Hemisphere	Scenario 3 Western Hem. & Asia	Scenario 4 Global adoption	Scenario 5 Productivity increase where growing season is 61-120 days
			Percentage difference from the baseline		
Oilseeds	1.361	2.061	1.471	-1.541	-1.851
Wheat	2.215	3.542	2.475	6.306	5.358
Other grains	3.260	3.910	3.390	1.520	4.310
Paddy rice	-2.021	-1.127	0.428	4.135	4.023
Other crops	1.854	2.661	2.063	5.092	-0.022
Livestock	1.050	2.230	0.822	2.893	0.012

[1] Scenarios 1-4 are for the adoption Bt corn and HT soybeans with yield and cost effects and cost effects only, respectively. Scenario 5 is an alternate scenario in which productivity for only one AEZ is increased (see Table 4).

Figure 1. Global Area Planted in GE Crops, 2005 (Million acres)



Source: ISAAA (2005).

Figure 2.

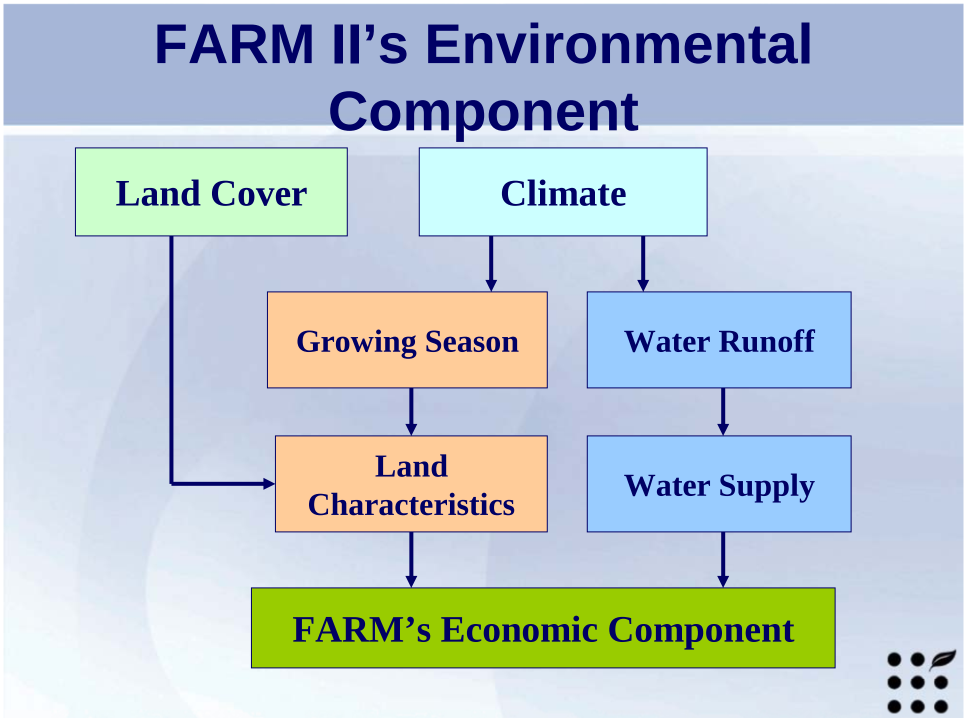

FARM II's Environmental Component
Land Cover
Climate
Growing Season
Water Runoff
Land Characteristics
Water Supply
FARM's Economic Component

Figure 3.

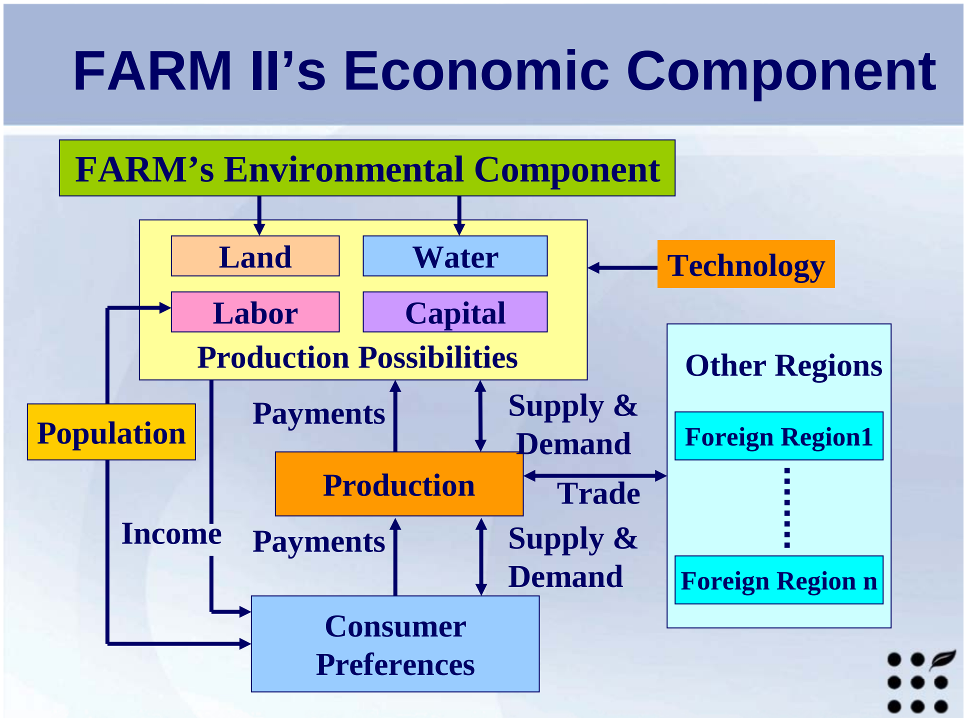

FARM II's Economic Component
FARM's Environmental Component
Land
Water
Labor
Capital
Production Possibilities
Technology
Other Regions
Foreign Region1
Foreign Region n
Population
Payments
Supply & Demand
Production
Trade
Income
Payments
Supply & Demand
Consumer Preferences

Figure 4.

Rainfed Agro-Ecological Zones in 1997

Derived from: University of East Anglia. Climate Research Unit. *CRU05 0.5 Degree 1901-1995 Monthly Climate Time-Series*. East Anglia, Great Britain.