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Modeling International Trade Impacts of Genetically Modified Wheat Introductions

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Abstract

Planned introductions of genetically modified crop varieties can be troublesome to model. Estimation of demand and supply equations is not feasible due to lack of data. Further, specifying demand and supply equations requires calibration to a presumed equilibrium. Depending on the point chosen, highly questionable results may be obtained. We propose a model that uses existing supply, demand, and elasticity estimates. The approach relies on composite supply and demand functions. These composite functions are linear combinations of GM and non-GM varieties. We then employ this approach in a model of world wheat trade to analyze the impact of several plausible GM wheat adoption and consumer acceptability scenarios.

Keywords: international trade, genetically modified organisms, producer surplus, consumer surplus, welfare, transportation cost

Highlights

Given recent controversies regarding genetically modified (GM) commodities found in U.S. food products and the reluctance of importers of U.S. commodities to accept GM varieties, the introduction of new GM crops appears troublesome. This is particularly so when the crop, such as wheat, is intended primarily for human consumption. Although not yet available, GM wheat varieties are scheduled to be available as early as the 2002 or 2003 growing season. These first releases, as with other GM crops, will be tolerant to glyphosate herbicide. Glyphosate-tolerant wheat increases the flexibility of herbicide application timing and the ability to control a wide range of weed species, both broadleaves and grasses. While herbicide-tolerant wheat varieties offer U.S. producers improved weed control, there is enormous downside potential to GM wheat introductions. There is potential for lost access to some markets and profits. This downside is magnified if the U.S. grain handling system is unable to maintain segregation of GM and non-GM varieties of the same commodity. The smallest detected levels of GM material can cause an entire shipment to be rejected by an end-user. A loss of confidence in the ability of the United States to segregate GM and non-GM wheat could shut all U.S. producers out of many overseas markets. Importers, fearing contamination within the grain handling and transportation system, will simply purchase wheat from non-GM producing countries. The end result would be that all U.S. producers could suffer large losses.

What remains unclear is how U.S. producers will be affected by the introduction of GM wheat varieties. Production costs, consumer acceptability, and the response of competing wheat-producing countries are all factors in the ultimate outcome of producer welfare. Further, consumers have the potential to gain or lose welfare due to these introductions. A lower cost of production wheat variety should result in lower consumer prices, but consumers, both domestic and foreign, benefit only if there is some acceptability of products made from GM wheat. Otherwise, some consumers may lose welfare if production shifts to less desirable, *i.e.*, GM, varieties.

Here we develop a mathematical programming model of the international market for wheat. GM wheat is introduced in the United States and other countries. The results indicate that U.S. producers stand to gain considerably due to GM introductions, assuming a 4.8% costs savings for GM vs. non-GM wheat. In most scenarios considered, U.S. producers would gain from adopting GM wheat. Only in the most widespread adoption scenarios do U.S. producers suffer from GM wheat introductions.

The results also indicate that foreign consumers, particularly in lesser-developed countries, would be the largest beneficiaries of GM wheat introductions. U.S. consumer welfare is relatively unchanged in the worst-case scenario, but generally improved in all other scenarios.

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Eric A. DeVuyst, Won W. Koo, Cheryl S. DeVuyst, and Richard D. Taylor*

Given recent controversies regarding genetically modified (GM) commodities found in U.S. food products and the reluctance of importers of U.S. commodities to accept GM varieties, the introduction of new GM crops appears troublesome. This is particularly so when the crop, such as wheat, is intended primarily for human consumption. Although not yet available, GM wheat varieties are scheduled to be available as early as the 2002 or 2003 growing season. These first releases, as with other GM crops, will be tolerant to glyphosate herbicide. Glyphosate-tolerant wheat increases the flexibility of herbicide application timing and the ability to control a wide range of weed species, both broadleaves and grasses. While herbicide-tolerant wheat varieties offer U.S. producers improved weed control, there is enormous downside potential to GM wheat introductions. There is potential for lost access to some markets and profits. This downside is magnified if the U.S. grain handling system is unable to maintain segregation of GM and non-GM varieties of the same commodity. The smallest detected levels of GM material can cause an entire shipment to be rejected by an end-user. A loss of confidence in the ability of the United States to segregate GM and non-GM wheat could shut all U.S. producers out of many overseas markets. Importers, fearing contamination within the grain handling and transportation system, will simply purchase wheat from non-GM producing countries. The end result would be that all U.S. producers could suffer large losses.

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Accurately modeling planned introductions is difficult. In a typical trade model, researchers specify systems of demands and supplies for each country and each commodity. Then, estimate relevant elasticities or rely on published estimates. Using these elasticity estimates and data on quantities and prices, demand and supply equation parameters are calibrated. But with GM commodities, existing data may be insufficient to allow estimation even for well-established GM corn and soybeans (Preckel et al.) For planned introductions, data are non-existent, as is the case for GM wheat. So, parameter values must be arrived at via fiat. After obtaining parameter estimates, the question is what quantities and prices should be used to calibrate demand and supply equations. These quantities and prices should represent an equilibrium. In the case of planned introductions, equilibrium cannot be observed from historical

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observation. So, researchers are left to speculate, not only about elasticity values, but the calibration point as well.

Preckel et al. propose primal/dual positive mathematical programming, an improved version of positive mathematical programming (Howitt), to model changes in producer profitability due to changes in export demand. This approach works well when at least one observation on quantities and prices exists, but is less well-suited to the case of planned introductions.

In this report, we develop a multinational trade model to consider the potential impacts of GM wheat releases. Each country's demand and supply are specified as linear composites of non-GM and GM wheat. In the composite functions, GM wheat quantities are multiplied by a parameter to scale up or down the marginal cost of production and marginal utility of consumption. Although these scaling parameters must still be arrived at by fiat, the model provides a framework for assessing the trade and welfare impacts of GM crop introductions without the need to estimate a new set of elasticities. Using this model, we then evaluate five plausible scenarios to assess the trade and welfare impacts of GM wheat introductions.

Literature

Previous research (Falck-Zepeda et al. 2000a,b; Moschini et al.) on GM crops indicates positive returns to consumers, producers, and GM developers. Falck-Zepeda et al. consider Bt cotton (2000a,b) and herbicide-tolerant soybeans (2000a). In 1996 and 1997, U.S. farmers, consumers, and rest-of-world (ROW) consumers all benefitted from U.S. adoption of Bt cotton. ROW Producers suffered losses. In 1997, U.S. soybean growers in aggregate realized additional profit from the adoption of herbicide-tolerant soybeans, but growers in Delta states suffered losses. Consumers, both domestic and ROW, realized additional surplus. Under various adoption scenarios, Moschini et al. show increases in U.S. producer surplus ranging from US$135 million to US$396 million from the adoption of GM soybeans. Increases in U.S. consumer surplus range from US$9 million to US$25 million. Increases in total world surplus range from US$804 million to US$2197 million.

Previous research concerning trade of GM products (Bredahl and Kalaitzandonakes; Ballenger et al.; Kalaitzandonakes) concludes that markets have been able to handle market segmentation issues. Bredahl and Kalaitzandonakes conclude that voluntary labeling has led to segmentation of GM and non-GM markets. Ballenger et al. argue that this segmentation has had little impact on supply and demand of GM crops. Kalaitzandonakes argues that markets are insulated from GM introductions as food processors typically arrange for non-GM suppliers. In markets with a non-GM preference, Bredahl and Kalaitzandonakes argue that domestic suppliers or substitute inputs will be used.

Model

A multinational/regional trade model for wheat is developed using GAMS (Brooke et al.). Table 1 presents the 17 major wheat importing/exporting countries and regions included in the model. All other countries are aggregated into the rest of the world (ROW). Also in Table 1, five-year averages of production, consumption and net exports are given for "common" wheat. Common wheat is a linear aggregation of wheat varieties used for baking, bread, noodles and livestock feed and excludes durum wheat.

Table 1. Five-year Average Common Wheat Production, Consumption, Net Exports, Income, and Population, 1995-1999

Country/ Region	Production (1000 MT)	Consumption (1000 MT)	Net Exports (1000 MT)	Per Capita Income (US$1000)	Population (million)
United States	61,287	31,547	29,433	23.96	275.19
Canada	22,661	7,050	13,852	17.83	31.31
EU	85,652	73,862	11,949	19.69	375.82
Australia	20,741	4,636	16,313	17.66	18.92
Argentina	12,960	4,636	8,335	2.23	36.90
Algeria	486	3,100	-2,650	2.80	32.16
Brazil	2,295	8,444	-6,115	0.80	175.94
China	112,135	114,943	-3,343	0.29	1,274.94
Egypt	5,792	12,562	-6,851	0.47	35.34
Japan	533	6,245	-6,053	38.34	126.46
S. Korea	8	3,790	-3,814	5.92	47.16
Mexico	3,283	5,064	-1,858	0.96	103.62
Morocco	3,164	5,154	-2,171	0.96	29.82
FSU	65,813	68,950	-2,880	4.20	295.90
Tunisia	89	878	-825	1.57	9.60
Taiwan	1	996	-992	10.11	22.13
Venezuela	0	863	-864	0.49	23.90
ROW	161,055	203,181	-40,980	1.39	3,054.96

Sources: Production, consumption, and net exports are from USDA/ERS. Income and population data are from the International Monetary Fund. ROW Per capita income estimated as average of the nine other less developed countries.

In the notation below, a subscript *i* denotes a consuming country or region. A subscript *j* denotes a producing country or region. In the model, each country *i* is assumed to have a demand for wheat. Wheat is a composite good made from a linear combination of non-GM and GM wheat, as in (1):

$$D_i = \sum_{j=1}^{18} \left(d_{i,j}^{non} + \beta_i d_{i,j}^{GM} \right) \tag{1}$$

where D_i is the composite good and $d_{i,j}^{non}$ and $d_{i,j}^{GM}$ are quantities consumed by country *i* and produced in country *j* of non-GM and GM wheat, respectively. Each country's demand function for the composite good is given as:

$$D_i = a_i + b_i \cdot Pricepd_i + c_i \cdot Income_i \tag{2}$$

where $Pricepd_i$ is the price paid by country *i* for the composite good and $Income_i$ is the per capita national income of country *i*. The parameters a_i, b_i and c_i represent intercept of the demand function, price responsiveness, and income responsiveness, respectively. Demand equation parameters are calibrated to elasticities and consumption and income data which are discussed below. Since consumers may differentiate GM from non-GM wheat demands, the marginal utility of GM wheat differs from the marginal utility of non-GM wheat by a factor of β_i. The parameter β_i can take any real, finite value. A value of zero indicates consumers are completely adverse to consuming GM wheat products. A value of one indicates complete acceptability. Any value between zero and one indicates a lower marginal utility of consumption for GM wheat products, but if the price is sufficiently low, consumption can occur.

Similar to demand, each country *j* produces a composite good which is a linear combination of non-GM and GM wheat. The composite good is given as:

$$S_j = \sum_{i=1}^{18} \left(s_{j,i}^{non} + \alpha_j s_{j,i}^{GM} \right) \tag{3}$$

where S_j is the quantity of the composite good and $s_{j,i}^{non}$ and $s_{j,i}^{GM}$ are quantities produced of non-GM and GM wheat produced by *j* and consumed by country *i*. The supply function of the composite good is given as:

$$S_j = e_j + f_j \cdot Pricerec_j \tag{4}$$

where $Pricerec_j$ is the price received by country *j* for the composite good. The parameters e_j and f_j are the intercept and slope of the supply function. Data used to calibrate these parameters are also discussed below. Equations (3) and (4) imply that producers of wheat may incur different marginal costs of producing GM vs. non-GM wheat. The α_j parameter in (3) is strictly positive. A value less than one indicates a lower marginal cost of production for GM wheat.

The model does not explicitly solve for prices paid and received for composite goods. Instead, we find these prices as marginal (*i.e*., shadow) prices of the composite goods produced and consumed. The model objective is to maximize total consumer and producer welfare minus transportation costs. This objective value is the sum of areas under the inverse of the composite demand functions minus the sum of areas under the inverse of the composite supply functions minus transportation costs, or:

$$\max_{d_{i,j},\, s_{j,i}} \sum_{i=1}^{18} \frac{D_i^2 - a_i \cdot D_i - c_i \cdot I_i \cdot D_i}{b_i} - \sum_{j=1}^{18} \frac{S_j^2 - e_j \cdot S_j}{f_j} - \sum_{i=1}^{18} \sum_{j=}^{18} \left(trans(i,j) \cdot d_{i,j}^{non} + trans(i,j) \cdot d_{i,j}^{GM} \right) . \tag{5}$$

The choice variables are quantities of GM and non-GM wheat consumed in each country and quantities of GM and non-GM wheat produced in each country. Balance constraints are imposed to insure the quantity of wheat, both GM and non-GM, exported from country *j* to country *i* equals the quantity of wheat imported by country *i* from country *j*, or:

$$d_{i,j}^{n} = s_{j,i}^{n};\ \forall i,j;\ n \in [non, GM] . \tag{6}$$

This also requires that the total amount consumed equals the total amount produced for both non-GM and GM wheat.[1] The United States is allowed to import wheat from Canada. Otherwise, exporting nations are constrained to consume only domestically produced grain. Importing nations are constrained to produce for only their domestic markets, buy may import wheat from any exporting country.

Data and Model Calibration

Data regarding production, consumption, net exports, population, and income are reported in Table 1. Per capita income and population data are taken from the International Monetary Fund. Wheat production, consumption, and net exports are from U.S. Department of Agriculture, Economic Research Service. Consumption data are then adjusted to ensure that production minus consumption equals net exports.[2] Distances between countries are taken from the U.S. Defense Mapping Agency and are reported in Table 2. Distances from each port to ROW are approximated by averaging the distance from each exporter to the four closest importing countries. Data regarding ocean freight rates are taken from the International Grain Council.

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[1] Note, this does not require the sum of composite consumption good to equal the sum of composite output. In fact, it will usually be the case that these two sums are not equal and, yet, equilibrium will still be achieved.

[2] As the data are five-year averages, this relationship does not hold for the raw data.

Table 2. Distances in Miles between Various Countries and Ports

	United States		Canada		Argentina	Australia	EU
Importer	Gulf	PNW	Vancouver	Thunder Bay	Buenos Aires	Brisbane	Rotterdam
Algeria	5,206	8640	8,803	4,667	5,700	10,271	1,843
Brazil	4676	7610	7,782	3,941	1,306	8,763	6,401
China	10,210	5240	5,351	13,047	11,931	4,243	12,954
Egypt	6,712	10,025	10,188	6,052	7,085	8,921	3,228
Japan	9,265	4,155	4,262	11,621	11,066	3,925	12,070
S.Korea	10,057	5,225	5,332	12,678	11,666	4,995	12,862
Mexico	789	4,669	4,782	4,141	5,726	8,897	4,842
Morocco	4,769	8,220	8,383	4,247	5,280	10,625	1,423
FSU	5,331	9,180	9,271	4,532	6,798	12,520	970
Tunisia	5,589	9,023	9,186	5,050	6,083	9,929	2,226
Taiwan	10,708	4,755	4,863	13,545	12,229	5,310	13,430
Venezuela	2,076	4,753	4,916	3,941	4,026	8,571	4,388
ROW*	6,282	6,785	6,927	7,431	7,408	8,081	6,386

Source: U.S. Defense Mapping Agency.
*Distances from ports to ROW are averages for each port.

Using 203 observations on transportation rates and distances, a log-linear relationship between rate ($/MT) and distance (miles) is estimated. The resulting estimation is:

(7) $$\log(rate) = 0.0515889 + 0.340405^{*} \log(miles)$$
$$(0.19201) \qquad (0.05342)$$
$R^2 = 0.16805$ F-stat = 40.60183^{*}
(*Significant at the 1% level).

where standard errors are given in parentheses. Using this estimated relationship and the data in Table 2, estimated transportation costs are generated. These costs are given in Table 3. Additionally, the United States is allowed to import wheat from Canada with a rail transportation cost of $5.30 per MT[3] (Park and Koo).

[3] Actual average shipping cost from Canada to the United States is $14.50/MT, and average shipping cost to Vancouver port is $9.20/MT. Since in-land shipping costs are not included in the shipping costs for other countries, the relative cost, *i.e.*, difference, is used.

Table 3. Estimated Transportation Costs

Importer	Exporter				
	United States	Canada	EU	Argentina	Australia
	--------------------------------US$ per 1000 MT------------------------------				
Algeria	19,397.482	18,679.430	13,614.634	19,995.092	24,433.059
Brazil	18,697.685	19,942.416	20,800.348	12,108.419	23,147.471
China	19,430.491	19,569.635	26,441.596	25,711.416	18,083.515
Egypt	21,138.996	20,407.139	16,476.438	21,531.771	23,288.705
Japan	17,954.962	18,111.040	25,812.994	25,061.061	17,610.262
S. Korea	19,411.540	19,545.953	26,377.521	25,515.577	19,116.342
Mexico	10,199.628	17,934.345	18,914.971	20,026.092	23,267.359
Morocco	18,817.411	18,089.317	12,467.275	19,480.855	24,716.520
FSU	19,544.705	18,493.716	10,942.507	21,230.808	26,136.644
Tunisia	19,861.685	19,187.735	14,518.412	20,442.662	24,153.020
Taiwan	18,798.588	18,942.856	26,768.407	25,928.246	19,518.463
Venezuela	14,177.694	17,634.666	18,291.553	17,763.227	22,973.566
ROW	15,255.992	17,942.342	12,885.707	18,582.146	17,336.898

Table 4 presents the demand, supply, and income elasticities for each country/region. These elasticities are from Benirschka and Koo. Supply and income elasticities for ROW are estimated by averaging across lesser developed countries (Algeria, Brazil, China, Egypt, Mexico, Morocco, the FSU, Tunisia, and Venezuela).

The base price for wheat is assumed to be $154/MT. Demand parameters are calibrated using this base price plus one-half of average transportation costs across all exporting countries. Supply parameters are calibrated using this base price minus one-half of average transportation costs across all importing countries.[4] The calibrated parameters for demand and supply are given in Table 5.

[4] Exporters and importers typically each pay some portion of the transportation margin, as the transportation cost acts essentially like a per unit tax. So, it is necessary to calibrate on prices that include the transportation margin.

Table 4. Demand, Supply, and Income Elasticities for Common Wheat

Country/Region	Demand	Supply	Income
United States	-0.059	0.220	0.358
Canada	-0.125	0.104	0.389
EU	-0.082	0.025	0.138
Australia	-0.302	0.074	0.471
Argentina	-0.179	0.165	0.433
Algeria	-0.165	0.000	0.597
Brazil	-0.148	0.185	0.297
China	-0.072	0.037	0.233
Egypt	-0.050	0.106	0.433
Japan	-0.005	0.000	0.358
S. Korea	-0.090	0.000	0.323
Mexico	-0.034	0.059	0.883
Morocco	-0.073	0.037	0.105
FSU	-0.134	0.130	0.527
Tunisia	-0.035	0.000	0.543
Taiwan	-0.162	0.000	0.645
Venezuela	-0.077	0.000	0.502
ROW	-0.100	0.062	0.458

Source: Benirschka and Koo.

Table 5. Calibrated Demand and Supply Parameters

Country	Demand Parameters*			Supply Parameters**	
	a	*b*	*c*	*e*	*f*
United States	33,691.947	-0.012	1.730	47,803.860	0.088
Canada	9,800.681	-0.007	6.138	20,304.256	0.015
EU	79,719.582	-0.039	1.374	83,510.700	0.014
Australia	5,655.024	-0.009	6.242	19,206.166	0.010
Argentina	5,398.603	-0.005	24.337	10,821.600	0.014
Algeria	3,595.225	-0.003	20.791	486.000	0.000
Brazil	9,640.483	-0.008	17.746	1,870.425	0.003
China	123,771.311	-0.054	72.777	107,986.005	0.027
Egypt	13,191.366	-0.004	178.263	5,178.048	0.004
Japan	6,600.285	-2.1E-4	0.486	533.000	0.000
S. Korea	4,139.803	-0.002	4.422	8.000	0.000
Mexico	5,271.985	-0.001	45.635	3,089.303	0.001
Morocco	5,705.670	-0.003	19.568	3,046.932	7.6E-4
FSU	77,775.519	-0.060	29.129	57,257.310	0.056
Tunisia	894.292	-2.1E-4	32.929	89.000	0.000
Taiwan	1,124.924	-0.001	2.863	1.000	0.000
Venezuela	912.380	-4.3E-4	37.036	0.000	0.000
ROW	222,742.753	-0.132	21.780	151,141.170	0.064

*Demand equation parameters are *a* = intercept, *b* = price responsiveness, and *c* = income responsiveness.
**Supply equation parameters are *e* = intercept and *f* = price responsiveness.

Baseline and Counter-factual Experiments

For the baseline model, GM wheat is not produced (all α_j>1) or consumed (all β_i=0), so all production and consumption is of non-GM wheat. The baseline production, consumption, and surpluses are given in Table 6. These results are the basis for comparison for the counter-factual experiments below. In Table 7, net exports under the baseline and counter-factual scenarios are presented.

Table 6. Baseline Production, Consumption, and Surpluses

Country/ Region	Production (1,000MT)	Consumption (1,000MT)	Producer Surplus (1,000,000US$)	Consumer Surplus (1,000,000US$)
United States	60,513.00	31,961.89	7,861.54	41,853.84
Canada	22,484.60	8,891.42	3,048.10	5,528.30
EU	85,562.04	73,956.91	12,471.53	69,685.93
Australia	20,619.74	4,533.65	2,824.96	1,183.50
Argentina	12,808.35	4,683.71	1,690.46	2,040.34
Algeria	486.00	3,595.23	0.00	1,406.38
Brazil	2,298.27	8,400.40	323.46	4,365.45
China	112,294.42	115,158.54	17,613.14	122,813.76
Egypt	5,827.40	12,606.55	896.28	19,357.92
Japan	533.00	6,600.29	0.00	101,387.01
S. Korea	8.00	3,814.48	0.00	3,243.38
Mexico	3,284.71	5,139.46	495.13	11,635.75
Morocco	3,168.56	5,319.83	497.23	5,595.32
FSU	66,061.48	68,425.67	9,771.23	39,165.83
Tunisia	89.00	894.29	0.00	2,002.99
Taiwan	1.00	986.32	0.00	464.70
Venezuela	0.00	861.69	0.00	859.39
ROW	161,468.02	201,677.28	25,073.48	154,643.05
TOTALS	557507.59	557,507.59	82,565.86	587,232.86

Table 7. Net Exports Under Baseline and Counter-factual Experiments

Country/ Region	Baseline	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
	---			1000 MT		---
United States	28,551.12	30,686.90	30,051.40	31,107.13	30,732.08	30,621.06
Canada	13,593.18	13,537.43	13,623.34	13,849.62	13,770.05	13,543.22
EU	11,605.12	11,389.30	11,167.16	11,034.55	12,632.07	11,392.98
Australia	16,086.09	16,010.36	15,932.42	15,885.87	16,266.00	16,011.65
Argentina	8,124.64	8,046.43	8,248.40	8,198.33	8,129.19	8,047.76
Algeria	-3,109.23	-3,109.23	-3,109.23	-3,109.23	-3,109.23	-3,109.23
Brazil	-6,102.13	-6,146.15	-6,161.62	-6,189.23	-6,227.35	-6,145.40
China	-2,864.12	-3,192.75	-1,158.72	-1,363.48	-1,646.27	-3,187.15
Egypt	-6,779.14	-6,806.86	-6,842.68	-6,866.01	-6,893.90	-6,804.87
Japan	-6,067.29	-6,067.29	-6,067.29	-6,067.29	-6,067.29	-6,067.29
S. Korea	-3,806.48	-3,815.55	-3,824.88	-3,830.46	-3,838.16	-3,815.39
Mexico	-1,854.75	-1,871.12	-1,877.10	-1,880.44	-1,888.68	-1,847.99
Morocco	-2,151.27	-2,164.63	-2,178.38	-2,186.59	-2,197.92	-2,164.40
FSU	-2,364.19	-2,832.49	-3,314.52	-3,602.35	-3,999.88	-2,824.52
Tunisia	-805.29	-805.29	-805.29	-805.29	-805.29	-805.29
Taiwan	-985.32	-989.75	-993.93	-996.53	-1,000.14	-989.49
Venezuela	-861.69	-864.65	-865.73	-866.33	-867.82	-864.54
ROW	-40,209.26	-41,004.67	-41,823.37	-42,312.26	-42,987.45	-40,991.12

In Table 8, values of alpha and beta parameters are reported for five counter-factual scenarios. Numerous articles discuss international concern about genetically modified crops and food inputs, but little quantitative information is known about consumer willingness to pay for genetically modified foods (Commandeur; Hoban 1997, 1999; McClusky; Zechendorf). As there is little empirical evidence to suggest values for alpha and beta parameters, we use plausible speculation, based on various data sources, to generate these values. In Scenario 1, we assume that the United States adopts production of GM wheat while other exporters do not. (Subsequent scenarios explore alternative adoption levels.) The marginal cost of producing GM wheat is assumed to be 4.8% lower than non-GM wheat. This is based on cost of production data for North Dakota wheat growers from the 1999 growing season. Herbicide costs for wheat on cash-rented land averaged \$11.36/acre and total direct expenses of \$92.86/acre (North Dakota Farm and Ranch Business Management). Taylor and Koo state that a single application of glyphosate costs approximately $6.90/acre, a cost savings of $4.46/acre or 4.8% of direct costs.[5]

Table 8. Counter-factual Experiments Parameter Values

Country/ Region	Scenario 1*		Scenario 2		Scenario 3		Scenario 4	
	α_j	β_i	α_j	β_i	α_j	β_i	α_j	β_i
United States	0.952	0.950	0.952	0.950	0.952	1.000	0.952	1.000
Canada	∞**	0.950	0.980	0.950	0.980	1.000	0.980	1.000
EU	∞	0.000	∞	0.000	∞	1.000	0.980	1.000
Australia	∞	0.000	∞	0.000	∞	1.000	0.980	1.000
Argentina	∞	1.000	0.980	1.000	0.980	1.000	0.980	1.000
Algeria	∞	1.000	∞	1.000	∞	1.000	∞	1.000
Brazil	∞	1.000	∞	1.000	∞	1.000	∞	1.000
China	∞	1.000	0.980	1.000	0.980	1.000	0.980	1.000
Egypt	∞	1.000	∞	1.000	∞	1.000	∞	1.000
Japan	∞	0.000	∞	0.000	∞	1.000	∞	1.000
S. Korea	∞	0.000	∞	0.000	∞	1.000	∞	1.000
Mexico	∞	1.000	∞	1.000	∞	1.000	∞	1.000
Morocco	∞	1.000	∞	1.000	∞	1.000	∞	1.000
FSU	∞	1.000	∞	1.000	∞	1.000	∞	1.000
Tunisia	∞	1.000	∞	1.000	∞	1.000	∞	1.000
Taiwan	∞	1.000	∞	1.000	∞	1.000	∞	1.000
Venezuela	∞	1.000	∞	1.000	∞	1.000	∞	1.000
ROW	∞	1.000	∞	1.000	∞	1.000	∞	1.000

*Parameter values for Scenario 5 are identical to Scenario 1 except that Mexico has $\beta_i = 0$ and is constrained to zero imports from the United States.
**Any alpha value greater than 1 will result in zero production of GM wheat.

[5] Cost savings may be smaller if suppliers of GM wheat charge a technology fee, as is done with corn and soybeans.

In Scenario 1, the beta parameters (*i.e.*, consumer acceptability) for lesser developed countries and Argentina are set to 1. This assumption follows Maslow's hierarchy of needs pyramid, which suggests that these populations are first motivated to satisfy basic physiological needs for food (Senauer). Hence, by setting beta to1 for these countries, we assume they will seek to feed their people at the lowest possible cost. Food safety concerns, including GM acceptability, are secondary to their caloric needs. The acceptability of GM-derived foods by U.S. consumers is high, despite recent recalls of food products tainted with GM commodities. In a recent survey, only 2% of U.S. respondents expressed concern about GM-derived foods (International Food Information Council Foundation) . This suggests that a large segment of United States consumers is not concerned with GM foods. Based on these study results, we choose a large beta, 0.95, for the United States. Hoban (2001) reports that perceived risks for genetically modified foods are similar for the United States and Canada. So, we also set the beta for Canada to 0.95. Other governments have been very reluctant to allow GM-derived foods. Representatives from the Japanese wheat industry recently stated that they will purchase non-GM wheat from U.S. competitors if the United States cannot ensure "GM-free" wheat (Gillam). Commandeur states that Japanese consumers prefer traditional food products and have previously paid premiums for a scarce traditional Japanese rice variety over importing rice from Thailand. We therefore initially set beta to 0 for Japan. South Korea follows Japan in its resistance to GM products. South Korea requires labeling of GM corn, soybeans, bean sprouts, potatoes, and food products containing those inputs (Cho). South Korea was the first country to restrict GM grains for animal consumption (Lence and Hayes). For these reasons, we initially set beta to 0 for South Korea. While levels of resistance to GM food products vary between countries of the European Union (EU), labeling regulations approved by the European Commission in January 2000 set a 1% trigger for GM products (Dyhrkopp and Schaefer). Because of this labeling restriction and steps taken by major European supermarket chains to eliminate GM products from their store shelves (Isaac and Phillips), we initially set beta to 0 for EU countries. The Australia and New Zealand Food Authority set GM labeling regulations after two major supermarket chains removed GM products from their shelves (ANZFA). Initially beta is set to 0 for Australia.

In Scenario 2, we assume identical consumer acceptability to Scenario 1, but in addition to the United States, allow Canada, Argentina, and China to produce GM wheat. These three countries currently produce large quantities of other GM crops and currently are the second, third, and fourth largest producers of GM crops. However, we assume that the cost savings these countries receive is lower than that for U.S. producers. Herbicide costs and/or use in these countries are often lower than in the United States (Taylor and Koo; United Nations, FAO). So, their percent reduction in costs, which we set at 2%, will be less than for U.S. producers. Scenario 3 is similar to Scenario 2 except we assume full consumer acceptability of GM wheat products. Scenario 4 examines the impact of adoption by all exporting countries and China with full world-wide consumer acceptance. The last simulation, Scenario 5, considers the impact of a lost U.S. export market due to U.S. adoption of GM wheat.

Results

Results from counter-factual experiments are compared to baseline producer and consumer surpluses from Table 6. Results for Scenarios 1 through 4 are reported in Tables 9 and 10. Results for Scenario 5 are reported in the text below. In Table 9, we report changes in welfare for producers and consumers in each country/region and in total for the world. In Table 10, we report GM production and consumption by country/region. When U.S. producers are the only adopters of GM wheat in Scenario 1, they enjoy a competitive advantage over other exporters, as a result of their lowered production costs. So, U.S. producer welfare increases, while producers in all other countries/regions suffer lower welfare. In total, producer welfare decreases by about US$1.7 billion, or about 2%. This is due primarily to the reduction in the world price of wheat. These producer welfare losses are more than offset by the gains to consumers worldwide. U.S. consumers suffer a slight decrease in welfare. Recall U.S. consumers have a marginal preference for non-GM wheat over GM wheat. Under Scenario 1, over one-half of the U.S. production shifts to GM wheat, effectively shifting the North American non-GM wheat supply curve left. The result is a slight increase in U.S. domestic wheat price. All other consumers benefit from the U.S. adoption of GM wheat. Increases in consumer surpluses total US$2.1 billion, or almost 0.4%, due again primarily to the reduction in world wheat prices.

Interestingly, the net EU welfare change is about -US$47 million. The decrease in world wheat prices harms EU producers. But, EU consumers benefit from these lower prices, even though EU consumers do not consume any GM wheat under this scenario. The increase in EU consumer surplus almost offsets the decrease in EU producer surplus. In fact, all consumers outside the United States benefit from price reductions due to U.S. adoption.

Also of interest is the distribution of consumer benefits. Consumers in the relatively economically advanced countries of the United States, Canada, the EU, Argentina, Australia, Japan and South Korea receive additional surpluses totaling about US$398 million, or about 19% of the improvement in consumer surpluses. The remaining 81% of improved consumer surplus is enjoyed by developing countries/regions, where it is most needed.

Results for Scenarios 2, 3, and 4 also show large gains for consumers. In Scenarios 2 and 3, the United States, Canada, Argentina, and China adopt GM wheat production. On the consumer side, Scenario 2 assumes only partial acceptability. In Scenario 3, we assume full consumer acceptance, and Scenario 4 has all exporters and China producing GM wheat. Accordingly, the gains in consumer welfare in Scenario 2 are smaller than Scenario 3 and smaller in Scenario 3 than in Scenario 4. In all three cases, however, collectively producers are unambiguously harmed by the GM adoption. This is due to wheat price falling more than the reduced cost of production, even for U.S. producers. In net, all these scenarios result in improved total welfare. Scenario 2, with partial consumer acceptance, yields almost US$1.3 billion in additional surplus. Scenario 3, with full consumer acceptance, yields US$1.7 billion in additional surplus. The largest gain, in Scenario 4, is almost US$2.3 billion. Again, the vast majority of benefits are enjoyed by consumers in developing countries. Consumers in these countries enjoy 79.5%, 75.8%, and 75.9% of the increased consumer surpluses under Scenarios 2, 3, and 4, respectively. In contrast, developing countries' producers suffer 31.3%, 30.0%, and 77.2% of the total reductions in surpluses under these three scenarios. The large losses suffered by developing countries in Scenario 4 are due in part to the assumption that there is little incentive for these producers to adopt GM wheat. As non-labor input use, including herbicides, tends to be lower than for industrialized countries, cost-savings associated with GM wheat are likely to be very small and may be more than offset by any increase in germplasm costs. As seen in these results, U.S. producers gain from GM adoption in all scenarios except 4, due to relatively large cost savings enjoyed by U.S. producers from GM adoption. These cost savings are, however, justified due to the relatively large dependence of U.S. producers on chemical inputs, including herbicides.

Table 9. Counter-factual Changes in Producer and Consumer Surpluses

Country /Region	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
	∆PS	∆CS	∆PS	∆CS	∆PS	∆CS	∆PS	∆CS
	--1,000,000 US$--							
United States	316.31	-4.17	98.99	79.68	189.50	343.84	-40.95	454.54
Canada	-55.79	22.10	-94.70	45.49	-119.10	95.87	-199.41	126.82
EU	-347.32	300.63	-704.57	610.75	-917.78	796.25	-742.60	1,052.86
Australia	-83.65	18.48	-169.57	37.65	-220.80	49.17	-183.56	65.17
Argentina	-51.90	19.06	-36.48	38.78	-69.65	50.59	-115.31	66.97
Algeria	0.00	14.60	0.00	29.63	0.00	38.60	0.00	50.99
Brazil	-9.31	34.18	-12.57	46.23	-18.38	67.76	-26.37	97.58
China	-455.76	468.06	-223.11	950.75	-514.69	1,239.44	-917.10	1,638.70
Egypt	-19.94	43.20	-45.64	99.12	-62.33	135.58	-82.25	179.21
Japan	0.00	26.80	0.00	54.39	0.00	70.86	0.00	86.08
S. Korea	0.00	15.48	0.00	31.44	0.00	40.99	0.00	54.21
Mexico	-22.45	35.20	-30.62	48.05	-35.19	55.24	-46.46	73.01
Morocco	-12.86	21.62	-26.08	43.92	-33.97	57.26	-44.86	75.70
FSU	-267.79	278.34	-542.47	565.87	-706.03	738.06	-931.35	976.48
Tunisia	0.00	3.28	0.00	7.02	0.00	9.60	0.00	12.68
Taiwan	0.00	4.18	0.00	8.15	0.00	10.64	0.00	14.08
Venezuela	0.00	5.91	0.00	8.07	0.00	9.28	0.00	12.26
ROW	-655.12	820.02	-1,328.33	1,666.31	-1,729.79	2,172.76	-2,283.59	2,873.58
TOTALS	-1,665.57	2,126.98	-3,115.16	4,371.30	-4,238.22	5,981.80	-5,613.81	7,910.94
NET	461.41		1,256.13		1,743.58		2,297.13	

Table 10. GM Wheat Production and Consumption

Country/ Region	Consumption of GM Wheat				
	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
	--1000 MT--				
United States			32,092.91	32,134.97	
Canada			8,968.18	8,992.93	
EU				74,513.52	
Australia				4,656.81	
Argentina		4,728.01	4,741.43	4,759.96	
Algeria				3,109.23	
Brazil		5,398.60	5,398.60	5,398.60	
China		114,444.70	114,374.69	115,924.27	
Egypt	6,806.86	6,842.68	6,866.01	6,893.90	6,804.87
Japan				6,067.29	
S. Korea				3,838.16	
Mexico	1,871.12	1,877.10	1,880.44	1,888.68	
Morocco				2,197.92	
FSU				3,999.88	
Tunisia		397.29	805.29	805.29	
Taiwan	989.75			1,000.14	954.93
Venezuela	864.65	865.73	866.33	867.82	864.54
ROW	33,691.95	35,778.72	36,547.79	42,987.45	33,691.95
	Production of GM Wheat				
United States	44,224.32	36,434.77	63,200.04	62,867.05	42,316.29
Canada		7,239.98	22,817.80	22,762.88	
EU				87,145.58	
Australia				20,922.81	
Argentina		12,213.39	12,149.14	12,060.40	
China		114,444.70	114,374.69	114,278.00	

Results in Scenarios 2, 3, and 4 are counter to those found by Falck-Zepeda et al. (2000a) and Moschini et al. for glyphosate-tolerant soybeans and Falck-Zepeda *et al.* (2000a,b) for Bt cotton. They report that consumers and adopting producers all benefit from the introduction of GM soybeans and cotton. Our simulation results in lower surpluses to producers following adoption of GM wheat by multiple producing nations. While counter to results for other GM crops, the result is economically plausible. Consider the profit function of country *i*:

$$\pi_i = p_i(q_1(\gamma_1), q_2(\gamma_2), \ldots, q_{18}(\gamma_{18})) \cdot q_i(\gamma_i) - TC(q_i(\gamma_i)) \tag{10}$$

where output q_i is an increasing function of technology parameter γ_i, the price received p_i is a decreasing function of all other producing nations' output, and total cost is increasing in output. The change in profits to *i* due to a technology change in *j* is:

$$d\pi_i = \left[\frac{\partial p_i(\cdot)}{\partial q_j} \frac{\partial q_j(\cdot)}{\partial \gamma_j} q_i + p_i \frac{\partial q_i(\cdot)}{\partial \gamma_j} - \frac{\partial TC(\cdot)}{\partial q_i} \frac{\partial q_i(\cdot)}{\partial \gamma_j} \right] d\gamma_j \, . \tag{11}$$

The first term in brackets is the change in profit due to a decrease in the equilibrium price that *i* receives as technology improves in *j*. The second term in the brackets is the change in *i*'s revenue due to the technology adoption by *j*. As *j* increases output due to technology adoption, this increases world supply and decreases the residual demand available to *i*. The final term is the change in *i*'s total costs due to *j*'s adoption. For $i \neq j$, this term is negative. The net change in profit, when $i \neq j$, is clearly negative. In Scenario 1, this is effect on profits for all countries other than the United States. If $i = j$, the total effect must be positive to induce change. This is the effect on U.S. profits in Scenario 1 and can be seen in Figure 1a.. In Figure 1a, country *i* alone adopts GM wheat. This adoption results in a increase supply from s_i^0 to s_i^1. Price decreases from P^0 to P^1. The result is that country *i*'s producer surplus decreases by P^0ACP^1 and increases by 0CB. In net, country *i* enjoys a net positive change in producer surplus.

Now consider the impact on *i* of multiple countries, including possibly *i*, of technology adoption:

$$d\pi_i = \sum_j \left[\frac{\partial p_i(\cdot)}{\partial q_j} \frac{\partial q_j(\cdot)}{\partial \gamma_j} q_i + p_i \frac{\partial q_i(\cdot)}{\partial \gamma_j} - \frac{\partial TC(\cdot)}{\partial q_i} \frac{\partial q_i(\cdot)}{\partial \gamma_j} \right] d\gamma_j \, . \tag{12}$$

In this case, even though *i* adopts the technology, the overall impact on the price *i* receives may offset the benefits from adopting the technology. The total change in output for an individual adopter may even be negative. The reduction in an adopter's surplus can be seen graphically in Figure 1b. In Figure 1b, country *i* adopts a new technology causing *i*'s supply function to change from s_i^0 to s_i^1. However, as other countries adopt the technology, the world's supply function changes from S^0 to S^2. The resulting change in producer surplus is equal to the area OFE - P^2P^0AF, which in this case is negative. Note, however, that the reduction in surplus is less than it would be if country *i* did not adopt the technology while other producing countries did.

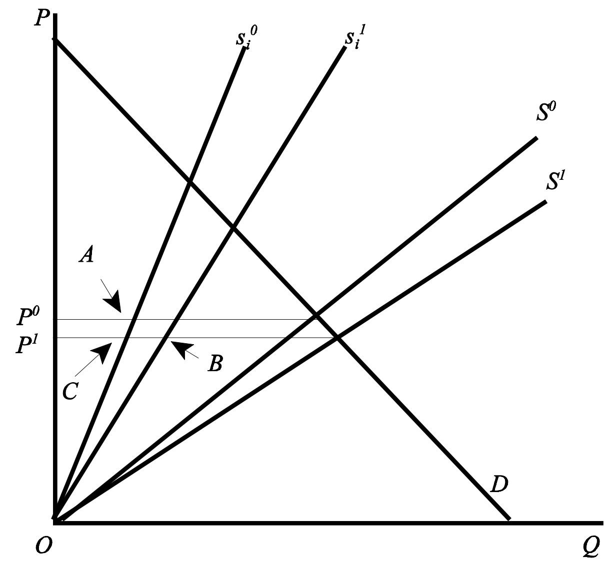

Figure 1a. Impact of U.S. Adoption of GM Wheat

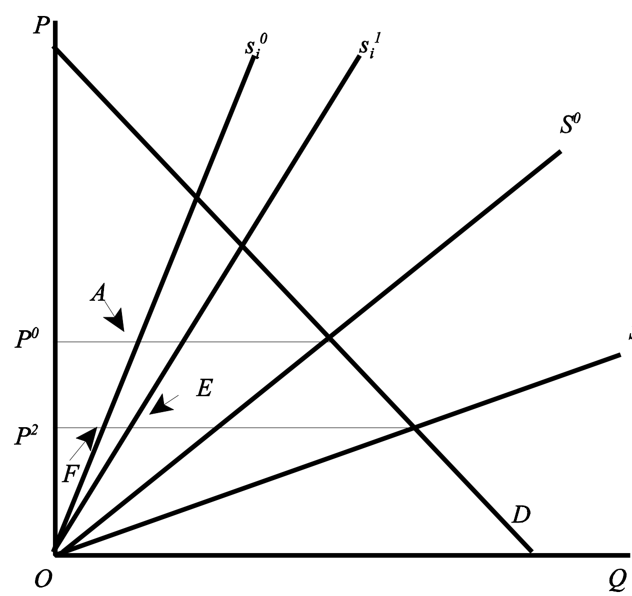

Figure 1b. Impact of U.S. and Multiple Country Adoption of GM Wheat

One final note on these simulations, in Scenarios 1, 2, and 3, EU producers are hurt more than EU consumers benefit. This is due to the assumption that EU producers will be prohibited from adopting GM wheat varieties. Since the EU is constrained from importing GM wheat, no GM consumption occurs in the EU. When EU producers are allowed to produce GM wheat, as in Scenario 4, net EU welfare increases, although EU producers still have lower surpluses relative to the baseline.

In Scenario 5, we investigate the impact of lost U.S. export markets in response to U.S. adoption. As is mentioned previously, there are concerns that importers of U.S. wheat may lose confidence in the United State's ability to maintain segregated market channels for GM and non-GM wheat. This loss of confidence could lead to some importers shifting away from U.S. wheat to wheat from non-GM producing countries. To simulate this effect, we allow U.S. production of GM wheat while restricting exports to one of the U.S. importers (Mexico) under the baseline to be equal to zero. That is, we use Scenario 1 parameter values and fix U.S. exports to Mexico to zero. The results are somewhat surprising. Initially, we expected the United States to lose producer surplus as the closest export market (from the baseline) was lost. However, the reduction in production costs and increased sales of GM wheat exported elsewhere more than offset the lost revenue. The resulting increase in U.S. producer surplus is US$319.15 million. We also initially expect Canadian producers to enjoy an increase in surplus. Even though Canada is able to increase exports to Mexico, Canadian producers suffer a loss of US$49.99 million due to reduced wheat prices in their other export markets. The U.S. share of the export market is very large, about 36.6% in the baseline. The reduction in U.S. production costs results in a significant reduction in world wheat prices. Producers in Mexico enjoy an increase in surplus, as the local price of wheat increases, of US$9.28 million, while Mexican consumers lose US$14.51 million. Producers worldwide lose almost US$1.6 billion and consumers worldwide gain over US$2.0 billion, for a net benefit of US$437.0 million.

Summary and Conclusions

Modeling of planned GM crop introductions is troublesome. Data on both production and consumption do not exist, precluding the use of econometric methods. We propose a method that utilizes elasticity estimates from existing crop varieties and composite supply and demand functions. These composite functions allow for differences in the marginal cost of producing GM vs. non-GM varieties and in the marginal benefits from consuming GM vs. non-GM varieties. We use the model to investigate international trade of wheat following GM wheat introductions.

Using planned GM wheat releases, we demonstrate the impact on international trade flows for five plausible scenarios. The results indicate that the United States may have a first-mover advantage even when importers of U.S. wheat do not accept GM wheat. This calls into question recent efforts by some state legislatures, such as North Dakota, to ban production of GM wheat varieties. If the savings in production costs are large enough, even the loss of some large export markets may not offset these cost savings. In the scenarios considered, U.S. producers enjoy additional surplus in all but the most widespread adoption scenario. As Canada, Argentina, and China, currently large producers of other GM crops (corn, soybeans, and/or canola), adopt GM wheat, the U.S. advantage diminishes. Add adoption by the EU and Australia and U.S. producers are harmed relative to the baseline. The widespread adoption of GM wheat reduces world wheat prices to a level where all producing nations lose surplus. In all the scenarios considered here, GM wheat introductions result in large consumer surplus increases. These gains more than offset aggregate producer losses. These results confirm that the long-run impact of biotechnology is to the benefit of consumers world wide.

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