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Optimal Production and Trade for Agricultural Products

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Abstract

A spatial equilibrium trade model was developed to evaluate optimal production of wheat (HRW, spring, and soft), corn, and soybeans in exporting countries and their market shares in the World Market on the basis of principles of comparative and competitive advantage in terms of production and marketing costs.

This study found that the United States has a competitive and comparative advantage in producing and marketing HRW, wheat, corn, and soybeans and has disadvantage in producing and marketing spring and soft wheat. This implies that the U.S. could increase its market share in HRW, corn, and soybeans under a free trade system and could lose its market share in spring and soft wheat.

Optimal Production and Trade for Agricultural Products

Agricultural trade in the mid-1970s experienced an unprecedented period of growth. During this period, the United States increased its export market share in many agricultural commodity markets. Since 1981, however, export market shares for agricultural products have steadily declined.

Many factors contributed to the fall of agricultural trade in the 1980s. A study conducted by the Office of Technology Assessment (1986) identified five major factors; (1) World economic recession, (2) an overvalued dollar, (3) increased government intervention, (4) developing countries shifting to greater self-sufficiency, and (5) adaptation of new farming technology in competing exporting countries. Factors one, two, and three are temporary economic phenomena based on economic policies in importing and exporting countries. A large body of literature has examined the impacts of economic issues on agricultural trade (Alouze et al.; Batten and Luttrell; Schuh; and Sharples). Factors four and five are production-related trade issues based on principles of comparative and competitive advantages. The limited number of studies analyzed competitiveness of U.S. Agricultural products in terms of production and marketing costs in the World Market (Ortmann et al.; Stanton; Koo et al.; Bowden).

The main objective of this study is to optimize production and trade activities of agricultural products on the basis of principles of comparative and competitive advantage. This study includes the principle of comparative advantage by allowing trade among exporting countries in addition to trade between exporting and importing countries and also includes the principle of competitive advantage by allowing competition among exporting countries in each importing region.

Spatial Equilibrium Model

A spatial equilibrium model for world trade of wheat, corn, and soybeans is developed on the basis of a mathematical programming algorithm. In this model wheat is divided into three different categories: winter wheat, spring wheat, and soft wheat. The model determines optimal production of the crops in each producing region in exporting countries and optimal distribution of these crops from producing regions to domestic and/or foreign importing regions. The criterion used in the model is to minimize production costs of the crops produced in exporting countries and marketing costs of shipping the crops from each producing region in exporting countries to domestic consuming regions in the countries and importing countries. The model is optimized subject to a system of linear constraints including arable land in producing regions and demand for each crop in domestic and foreign importing regions. The model consists of six exporting countries and 64 importing countries divided into 17 importing regions. Of the six exporting countries, the United States has 18 producing regions, Canada has 3 producing regions and Argentina, Brazil, Australia, and France have 1 producing region.

All exporting countries are also divided into domestic consuming regions. The United States is divided into 24 regions, Canada--two regions, and all other exporters--one consuming region. Consuming regions in the United States were chosen by location of wheat and corn mills and soybean processing plants. Other countries' domestic consuming regions were determined as urban centers with the greatest population.

Trade originates from export ports within each exporting country. The model includes five exporting ports in the United States, two in Canada, and one for each in all other countries. Importing port centers for all regions were chosen as centralized positions based on distance.

The objective function of the model is written as follows:

$$\text{Min } {}^*C = \sum_{a=1}^{6} \left[\left(\sum_{c=1}^{b} \sum_{j=1}^{k} \left[(PC_{acj}\ L_{acj}) + \sum_{i=1}^{h} (C_{acij}\ X_{acij}) \right. \right. \right.$$

$$\left. \sum_{e=1}^{f} (C_{acej}\ X_{acej}) \right] + \sum_{c=1}^{b} \sum_{e=1}^{f} \sum_{m=1}^{n} (C_{acem}\ X_{acem}) \Big] \qquad 1)$$

where;

PC_{acj}	=	production cost of one hectare of commodity c in producing region j of country a;
L_{acj}	=	number of hectares used in producing commodity c in producing region j in country a;
C_{acij}	=	transport cost per metric ton (mt) of commodity c from producing region j to consuming region i in country a;
X_{acij}	=	quantity in mt of commodity c transported from producing region j to consuming region i in country a;
C_{acej}	=	transport cost per mt of commodity c from producing region j to export port e in country a;
X_{acej}	=	quantity of commodity c shipped from producing region j to export port e in country a;
C_{acem}	=	transport cost per mt of commodity c from export port e to importing region m;
X_{acem}	=	quantity in mt of commodity c transported from export port e of country a to importing region m.

The objective function in Equation 1 is the summation of four separate activities of all six exporting countries. The first summation of Equation 1 represents production costs of each commodity by producing region measured in dollars per hectare. The three activities associated with transshipment of grains are (1) shipments from producing regions to consuming regions, (2) those from producing regions to export ports, and (3) those from export ports to importing regions. All costs of these activities are measured in dollars per metric ton.

Five linear constraints are placed on the above model as follows:

$$DD_{aci} = \sum_{j=1}^{k} X_{acj} \qquad 2)$$

$$MD_{cm} = \sum_{a=1}^{6} \sum_{e=1}^{f} X_{acem} \qquad 3)$$

$$L_{acj}\, Y_{acj} = \sum_{i=1}^{h} X_{acij} + \sum_{e=1}^{f} X_{acem} \qquad 4)$$

$$TL_{aj} \geq \sum_{c=j}^{b} L_{acj} \qquad 5)$$

$$\sum_{j=1}^{k} X_{acej} = \sum_{m=1}^{n} X_{acem} \qquad 6)$$

where;

DD_{aci}	=	demand for commodity c in consuming region i in country a;
X_{acij}	=	quantity demanded of commodity c in consuming region i from producing region j in country a;
MD_{cm}	=	demand for commodity c in importing region m;
x_{acem}	=	quantity of commodity c demanded by importing region m from export port e in country a;
Y_{acj}	=	yield in mt per hectare in production region j for commodity c in country a;
TL_{aj}	=	total land available in production in region j in country a.

Equation 2 represents that domestic demand for grains in each consuming region must be met by the total quantities of grain shipped to this region. Equation 3 represents that the total quantity of each grain moved to an importing region must be equal to the commodity of the grain required in the importing region. Equation 4 refers to supply and demand equilibrium conditions indicating that the total quantities of crops produced in each producing region should be equal to the quantities shipped to domestic and foreign consuming regions. The land constraint presented in Equation 5 represents that the total land used in production should be limited to the quantity of available cropland in each production region. Equation 6 is an inventory clearing condition which forces all commodities shipped to exporting ports to be exported.

Data

The model requires costs associated with production activities (production costs), costs associated with domestic transportation activities (barge and rail costs), costs associated with exports (ocean shipping costs), yields and right-hand side (RHS) values associated with constraints (available arable land, domestic demand, and import demand).

Production Costs and Yields

Production costs for various countries are reported as average total variable costs to produce one hectare of crop. Variable costs are reported in crop enterprise budgets which list all cost factors used in the production process. Only variable costs of crop production are considered in this study because this study is an analysis of short-run spatial equilibrium. Production cost data for the U.S. were taken from an ERS publication entitled "State Level - 1985 Cost of Production" (McElroy 1986). Average production cost of crop c in region i was a weighted average of the state production costs based on total state acres planted in the region.

United States production yields were obtained from USDA data reported in Grain Market News (USDA 1986). A three-year average, 1984-1986, was used for all regional average yields.

France, in this study, has only one producing region--the Paris Basin. Four-year data, 1980-1983, collected by Stanton and reported in 1982 constant francs were used (Stanton 1986). A simple average was calculated and inflated to 1986 French prices using the French consumer price index (CPI) (IMF 1987). These figures were then adjusted to 1986 U.S. dollars by using the average 1986 exchange rates (IMF 1986). An average yield per hectare for Paris Basin of 6.36 mt per hectare for soft wheat and 6.88 mt per hectare for corn was calculated for the same four years.

Production costs for Canadian Western red spring wheat were based upon a report written by Strain and Bandry (Strain and Bandry 1987). Canada was divided into three producing regions; (1) Alberta, (2) Saskatchewan, and (3) Manitoba. All costs in the Strain and Bandry report were given in 1987 Canadian dollars. Production cost in each region was deflated to 1986 prices by the Canadian CPI (IMF 1987). The production costs in 1986 Canadian dollars were converted to U.S. dollars by using the average 1986 exchange rate (IMF 1987).

Production cost data for all other countries were taken from a study by Ortmann et al. (1986). Argentina, Brazil, and Australia were represented in the model with only one producing region. It is assumed that Argentina produces and exports winter wheat, corn, and soybeans; Brazil produces and exports corn and soybeans; and Australia only produces and exports soft wheat in this study. Production yields for Argentina, Australia, and Brazil were taken directly from Ortmann (Ortmann 1986).

Marketing Costs

Marketing costs consist of shipping costs from producing regions to final destinations and handling costs at elevators and port terminals. The handling costs used are 12 cents per bushel at country elevator and 7 cents per bushel at port terminals. Shipping costs are divided into two components; (1) costs from producing regions to domestic consuming regions and (2) costs from producing regions to foreign importing regions through port terminals. It is assumed that grains are moved to domestic consuming regions by rail or truck, and are moved to port terminals by rail, barge, truck, or a combination of these and then moved to importing regions by ocean vessels. Rail, barge, and truck rates (for the United States and Canada) were obtained from a study by Koo and Thompson (1981) and adjusted to 1986 U.S. prices for the rates in the U.S. and adjusted to 1986 Canadian prices for the rates in Canada. For other exporting countries, marketing costs are the sum of average transportation rates from central production location to the port terminal and handling charge at the port. The marketing costs in each exporting country are converted to 1986 dollars by using the average exchange rates (IMF 1986). There were no sources for different ocean freight rates needed for this study. Accordingly, an ocean freight rate function was developed using average rates from 57 shipping rates reported in World Wheat Statistics (IWC 1985). These freight rates were regressed against one-way mileage to produce the following equation:

$$OFC_{in} = 14.668 + \underset{(89.09)}{0.00156}\, M_{in} \qquad 7)$$

$$R_2 = 0.533$$

where M_{in} is one-way mileage from the i^{th} export port the n^{th} importing regions and OFC_{in} is ocean freight rates from the i^{th} export port to the n^{th} import region. The t-value (the number in parenthesis) indicates that one-way mileage is statistically significant at the 1 percent level.

The shortest distance between exporting and importing ports was calculated (Defense Mapping Agency 1985), then ocean freights rates were calculated by using Equation 7.

Constraints

To calculate average available land for wheat and corn in each producing region in the United States, the set-aside acreage was added to total acres harvested of wheat and corn. These totals were then added to soybean harvested acreage. A three-year average from 1984 to 1986 was calculated and converted to hectares for use in this study.

Total available land in other exporting countries was defined as being 25 percent larger than average harvested acres for wheat, corn, and soybeans from 1984 to 1986. All data were taken from the FAO Yearbook of Production (1985) and Agriculture Canada (1987).

Total U.S. demand for 1984-1986 was taken from USDA Situation Outlook reports for wheat, corn, and soybeans (USDA 1984-1986). A three-year average was calculated and allocated to each consuming region on the basis of the total milling capacity in each region for food uses and the number of grain consuming animal units for feed uses. Total demand for wheat in Canada was based on data reported in World Wheat Situation (IWC 1986). A three-year average from 1984-1986 was calculated and allocated to two consuming regions on the basis of Canadian milling capacity for spring wheat (Flour Milling Association of Canada 1987). Domestic demand for wheat in Argentina, Australia, and France were obtained from World Wheat Situation (IWC 1986). Data for corn and soybeans in these countries were calculated as simply production less exports under an assumption that beginning stocks are a small portion of total supply.

Total imports for all importing regions were collected from various years of FAO Trade Yearbook. Annual imports for all countries in a given importing region were aggregated for the years 1983-1985 for corn and soybeans. These totals were then averaged to obtain total average imports for each region by crop. Wheat imports for all importing regions were based on data reported in World Wheat Statistics (1985-1986).

Results

Table 1 presents optimal quantities of each crop produced in producing regions in the United States, Canada, and other exporting countries. The total HRW wheat production is 44 million metric ton (mmt) in the United States, 12 mmt in Argentina, and 6.4 mmt in Brazil. The actual HRW wheat production in the United States was 28 mmt in 1986, implying that the United States should produce more HRW wheat than the current production level based on production and marketing costs. The total spring wheat production is 11 mmt in the United States and 26 mmt in Canada. The actual production in 1986 was 15 mmt and 24 mmt in the United States and Canada, respectively. On the other hand, the United States produces 13 mmt of soft wheat which is much larger than the actual production in 1986. France produces 22 mmt of soft wheat and Australia produces 16 mmt.

Corn production is largely concentrated in Iowa, Illinois, Nebraska, Minnesota, Wisconsin, Michigan, Indiana, and Ohio. The total quantities of corn produced are 217 mmt in the U.S., 6.8 mmt in France, 7.2 mmt in Argentina, and 20.7 mmt in Brazil. The optimal corn production in the United States is similar to actual production in 1986.

Soybean production is concentrated in Iowa, Illinois, Indiana, and Ohio. The total soybean production is 58 mmt in the United States which is similar to actual production in 1986. Brazil produces 14 mmt of soybeans and Argentina 4.3 mmt.

Utilization of arable land for crop production is also shown in Table 1. A ratio of land used for crop production to the total arable land in a producing region indicates the region's competitive advantage in producing and marketing agricultural products. On the other hand, a ratio of unused land to the total arable land in a producing region is interpreted as the region's competitive disadvantage in producing and marketing agricultural products. The total acres of arable land are fully utilized in Iowa, Illinois, Wisconsin, and Michigan, indicating that these states have a competitive advantage over other states and countries in producing and marketing agricultural products. In Canada, the total acres of arable land are fully used in Alberta and Saskatchewan.

The percentage of the unused land is very high in Washington, Oregon, North Dakota, South Dakota, and New England, indicating that these states have competitive disadvantage over other states and countries in producing and marketing agricultural products. The total acres of unused land is 28.2 percent of the total arable land in the United States, 10.3 percent in Canada, 27.8 percent in Australia, 45.8 percent in France, 24.2 percent in Brazil, and 27.7 percent in Argentina.

Exporting countries' market shares of each crop are shown in Table 2. Based on production and marketing costs, the U.S. market shares are 81 percent for HRW wheat, 93.5 percent for corn, and 93.9 percent for soybeans, which are much larger than the actual market shares in 1986. This implies that the United States could increase its market shares of HRW wheat, corn, and soybeans if world trade is determined by production and marketing costs under

TABLE 1. TOTAL PRODUCTION BY CROPS IN THE US AND OTHER EXPORTING COUNTRIES IN THE BASE MODEL

Region	Production						Utilization of Arable Land			
	HRW	Spring	Soft	Corn	Soybean	Total	Total Land	Land Used	Unused Land	% of Unused Land
1. WA, OR	--	--	3,663	--	--	3,663	2,884	1,009	1,875	65.4
2. CA, NV, UT, AR	2,571*	--	--	3,469*	--	6,040	1,404	816	588	42.4
3. MT, ID, WY	3,041*	3,186*	199	--	--	6,426	5,988	4,197	1,790	29.3
4. CO	4,631*	--	--	1,808	--	6,439	2,590	2,359	230	0.9
5. ND	275	4,782	--	989*	190*	6,236	7,878	2,757	5,121	65.2
6. SD	842*	892*	--	3,597*	1,004*	6,335	5,579	2,411	3,168	57.0
7. NE	3,393*	--	--	32,385*	1,174	36,952	6,950	6,514	436	6.1
8. KS	15,954*	--	--	1,969*	1,284*	19,207	9,689	8,301	1,388	14.3
9. OK	4,152	--	--	--	--	4,152	4,404	2,844	1,560	35.6
10. TX, NM	5,447	--	--	2,740*	--	8,187	7,643	2,675	4,968	65.2
11. MN	360*	1,706	--	26,987*	6,273*	35,326	366	7,571	7,937	5.4
12. IA, IL	--	--	1,821	75,222	26,856*	103,899	19,854	19,854	0	0
13. ARK, LA, MS, MO	--	--	--	8,597*	6,168*	14,765	10,131	4,788	5,344	53.9
14. WI, MI	--	--	2,020*	25,366	729	28,115	4,806	4,806	0	0
15. IN, OH	--	--	3,681*	20,218	10,513	34,412	9,048	8,275	773	8.3
16. KY, TN, WV, VA, NC	--	--	817*	6,815*	2,082*	9,714	4,972	3,027	1,945	39.2
17. AL, GA, SC, FL	--	--	--	4,876	1,409*	6,285	4,138	2,043	2,095	51.1
18. NY, PA, NJ, MD, DE	--	--	1,030*	1,492	675	3,197	2,788	975	1,813	65.4
US TOTAL	40,666	10,566	13,231	216,530	58,357	339,350	8,683	85,222	33,461	28.2
CANADA	--	26,197	--	--	--	26,197	6,159	14,492	1,667	10.3
AL	--	4,505	--	--	--	4,505	2,371	2,371	0	0
SA	--	17,358	--	--	--	17,358	10,151	10,151	0	0
MAN	--	4,334	--	--	--	4,334	3,637	1,970	1,667	46.8
France	--	--	21,699	6,772	--	28,471	8,116	14,396	3,720	45.8
Argentina	11,731	--	--	7,224*	4,313*	23,268	14,573	10,525	4,048	27.7
Australia	--	--	15,799	--	--	15,799	14,116	10,193	3,923	27.8
Brazil	6,432	--	--	20,702	13,863	40,997	29,908	22,669	7,239	24.2
TOTAL	58,829	36,763	50,729	251,228	76,533	474,082	199,555	147,497	52,058	26.1

a free trade system. The optional markets shares for spring wheat and soft wheat are 15.3 percent and 20.5 percent, respectively, in the United States which are smaller than the actual market shares in 1986. This indicates that the United States could lose its market shares of spring wheat and soft wheat to Canada and Australia, respectively, under a free trade system.

TABLE 2. QUANTITIES OF CROPS EXPORTED BY COUNTRIES

Country	HRW	Spring	Soft	Corn	Soybean	Total
United States	25,459	3,723	4,969	43,759	28,599	106,506
	(81.1)	(15.3)	(20.5)	(93.5)	(93.9)	(67.8)
Canada	--	20,586	--	--	--	20,587
		(84.7)				(13.1)
France	--	--	4,006	--	--	4,006
			(16.5)			(2.5)
Brazil	--	--	--	--	--	--
Australia	--	--	15,251	--	--	15,251
			(63.0)			(9.7)
Argentina	5,929	--	--	3,044	1,861	10,834
	(18.9)			(6.5)	(6.1)	(6.9)
Total	31,386	24,309	24,225	46,803	30,459	157,183

Concluding Remarks

A spatial equilibrium trade model was developed to evaluate optimal production of wheat (HRW, spring, and soft), corn and soybean in exporting countries and their market shares in the World Market on the basis of principles of comparative and competitive advantage in terms of production and marketing costs.

This study found that the United States has a comparative and competitive advantage over other countries in producing and marketing HRW wheat, corn, and soybeans, and has disadvantage in producing spring and soft wheat. The United States, Iowa, Illinois, Wisconsin, and Michigan have a greater advantage in producing and marketing agricultural products while Dakotas, Washington, Oregon, and New England have the least advantage in producing and marketing agricultural products.

Under a free trade system for agricultural products, the United States could increase its market shares for HRW, wheat, corn, and soybean and could lose its market shares for spring and soft wheat.

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