MODELING THE WORLD GRAIN-OILSEEDS-LIVESTOCK ECONOMY TO ASSESS WORLD FOOD PROSPECTS

By Anthony S. Rojko and Martin W. Schwartz*

Mathematical programming methods are used as a framework to evaluate world food prospects. Emphasis is on analyzing the world grain-oilseeds-livestock economy to capture the interaction of the predominantly cereal economies of the developing world and the livestock economies of the developed world as they compete for the world's agricultural resources. The mathematical model, called the Grain-Oilseeds-Livestock (GOL) model, incorporates general population and income growth rates, demand and supply price elasticities, input variables, and assumptions about basic underlying economic trends and policy constraints.
Keywords: Projections, grain-oilseed-livestock model, trade models.

A model of the world grain-oilseed-livestock economy (GOL) has been developed within the Economic Research Service (ERS) to generate projections of world food production, consumption, and trade to 1985 and 2000.[1] World equilibrium models exist for individual commodities or limited commodity aggregates, and individual country models integrate the grain, oilseed, and livestock sectors. The GOL model, however, is one of the first equilibrium models to consider the broader feed-livestock relationships at the regional and world level. It relates the grain-oriented food economies of developing regions with the livestock-oriented food economies of developed regions in a more complete and logically consistent manner than has been done in the past.[2]

GOL is an operational model used as an integral part of ongoing ERS projections work (*6*). The export projections tie in with detailed U.S. models. It is also used as an analytic tool providing a quantitative dimension to otherwise qualitative international policy analysis.

Using population and income growth rates, supply and demand elasticities, physical input-output rates, and policy assumptions as inputs, the model projects area, production, food and feed use, trade levels, and prices for each commodity. Eleven basic commodities are included: wheat, rice, coarse grains, oilmeal, soybeans, beef and veal, pork, poultry, milk, butter, and cheese. The world was divided into 27 regions: eight developed, three centrally planned, and 16 developing. All regions have some crop equations, but not all regions have livestock equations. The centrally planned regions have collapsed international trade equations only.

The equations in the model were developed to reflect (1) the economic behavioral patterns of the grain-oilseeds-livestock economy, (2) the important technical input-output relationships, and (3) the institutional setting and policy constraints. An attempt was made to model changes in consumption preferences (such as increasing desire for livestock products and increasing use of grain in livestock products and increasing use of grain in livestock production; changes in resource mixes, and changes in both crop and livestock productivity. The individual regional commodity coefficients were synthesized from existing studies and analyses, notably (*3, 5, 11-13, 14, 16, 18, 19, 23* and *24*).

MODEL STRUCTURE[3]

Within GOL, most commodities have supply, demand, and trade sectors modeled. The figure following shows the relationships among the endogenous variables for a typical region. The crop supply sector appears at the far

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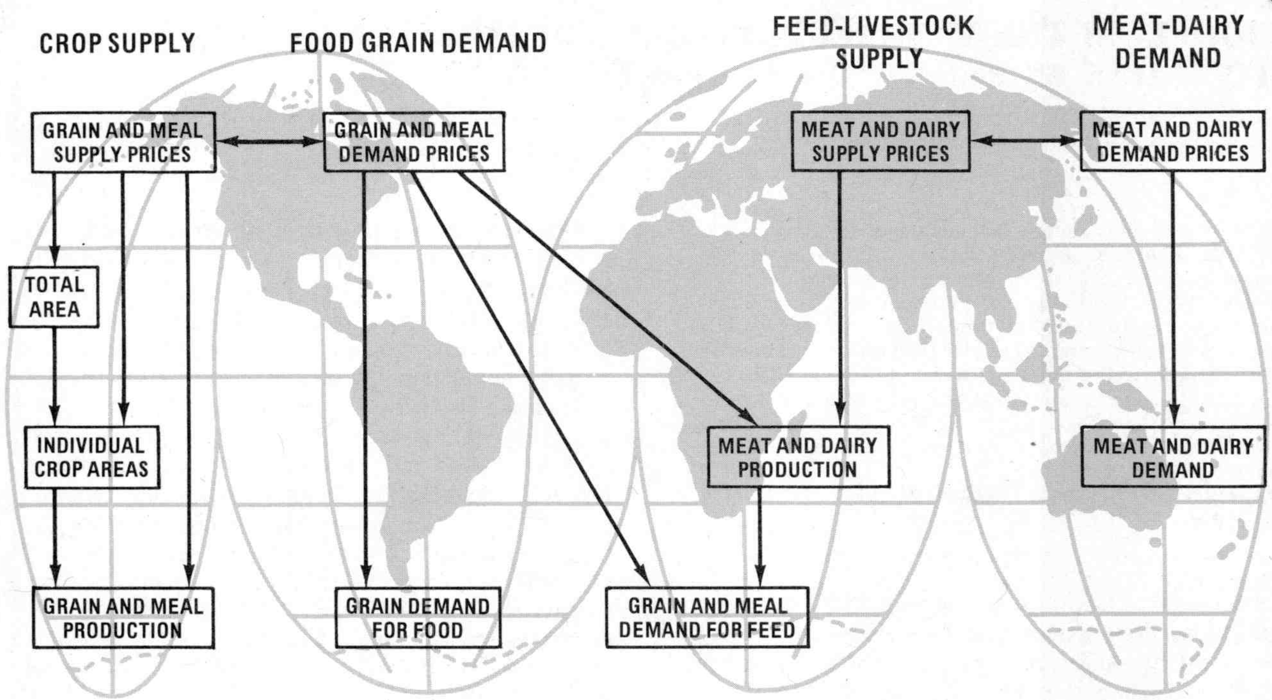
[1] This article reports on one phase of an ongoing research effort aimed at generating and maintaining up-to-date price, production, consumption, and trade projections for the major regions of the world. This effort requires substantial ongoing teamwork from members of the Commodities Program Area working with others in FDCD and other ERS divisions in the area of econometric model development and country-specific analyses. Significant inputs have been made by Donald Regier (livestock), Patrick O'Brien (grains), Arthur Coffing (oilseeds), Robert Barry (rice), Myles Mielke (dairy), and Linda Bailey. Several people have helped to develop the computer programs, beginning with Frances Urban in the early stages, Hilarius Fuchs during the main development stage, followed by Fenton Sands and Martin Schwartz. The work summarized here has been reported in detail in several other ERS publications–(*8, 20-22*). It was discussed in context with other ERS forecasting and projections models in (*6*).

Note: Italicized numbers in parentheses refer to items in References at the end of this article.

[2] A primary purpose in development of the model was to provide a quantitative basis for assessing the world food prospects of the developing world in the context of the total world grain and livestock complex. Several reports (*4, 9, 28*) have been concerned with this issue, as well as two ERS reports (*7*) and (*8*) that used results from this model.

[3] This model builds upon the world grain model developed by Rojko, Urban, and Naive (*20*). The approach has also been influenced by model development by Bawden (*2*), Judge and Takayama (*15, 26, 27*), and others (*10*).

SUPPLY AND DEMAND SECTORS FOR A TYPICAL REGION IN GOL MODEL



left of the chart. The key endogenous variable is total area, defined as a function of the prices for the region's most important crops. Individual crops compete for total area based on historic shares and projected relative prices of the crops. Production is determined from the area and from crop prices; prices are included to allow response to higher input use when prices are higher. Typical grain supply equations[4] for a region are:

Total area = F (wheat and other crop prices)
Wheat area = (total area, price of wheat, corn, and meal)
Wheat production = F (wheat area, wheat price, exogenous input bundle)

Grains demanded for human food are functions of grain prices, income, and population. The price elasticities allow variance in both total food demand for grain and the relative shares of individual grains. Demand for meats and dairy products, shown on the far right of the chart, are modeled similarly. Typical equations are:

Wheat demand for food = F (price of wheat, corn, price, rice; income; population)
Beef demand = F (price of beef, pork, and poultry; price, income; population)

[4] Note: Crop areas sum to total area in these equations.

The feed demand-livestock production sector, second from the right in the figure, is more complex. Meat production is a function of meat prices, feed prices, and productivity. The incorporation of individual meat prices allows competition between the meats. Grain and oilseed feed prices influence the cost of producing meats. Typical equations are:

Beef production = F (price of beef, pork, corn, and meal; productivity)

Feed demand is a function of appropriate grain prices, meat prices, and livestock production. Crop prices allow competition between feeds. The coefficients for livestock products are nominal feeding rates; that is, the tons of grain used to produce a ton of livestock products. Livestock product prices are used to adjust feed demand, essentially modifying the feeding rate, which forms a second set of relations between crop prices and livestock prices. Typical equations are:

Oilmeal demand for feed = F (production of beef, pork, poultry, eggs, and milk, price of pork, corn, and meal)

Supply and demand prices for crops and meats, shown as arrows in the figure, are usually related through constant margins. Price margins fluctuate, however, in the few selected regions where historical data indicates that margins widen, narrow, or do both, as price levels change.

Total milk production, similar to that of crops and meat, is a function of milk price, feed prices, and productivity growth. However, dairy products and prices are treated somewhat differently because of the physical production process. Total milk production is processed into cheese or butter or sold as fluid milk products. The supply function for fluid milk is, in fact, also the demand function because fluid demand is filled first. Thus, the function is defined as a function of milk price, income, and population. Production of cheese and butter depends on the relative demand for these products; thus, relative product prices and other demand factors determine their output. Cheese production is a function of cheese and butter price, population, and income. Population and income are included to reflect the continuing longrun growth in demand for cheese. Mathematically, butter production is treated as a residual. Through use of physical conversion factors, total milk production not required for fluid milk and cheese becomes butter. The supply prices of total milk, butter, and cheese and the demand price of fluid milk products are related to reflect product yield.

Economic activity between regions is related through trade prices and a world equilibrium for each commodity traded. The commodity-specific world equilibrium equations state that total world production minus total world demand equals the change in stocks. Stock changes are either predetermined or treated as residual, depending on the purpose of the particular simulation. Each region's import or export prices are related to the region's demand price, either through constant margins or through decreasing margins as trade prices increase. That is, it is assumed that whenever import prices increase, the entire increase will not be passed on to consumers. Finally, trade prices in the different regions are related.

GOL incorporates a number of exceptions to the treatment outlined above. These exceptions are included to more accurately model a particular region. For example, variable levies are included in the equations for the European Economic Community (EC). In addition, special equations linking the original six countries (EC-6) and the new members (EC-3), which are modeled as separate regions, are included to reflect the gradual harmonization provided for in the EC's Common Agricultural Policy. For major exporters, the unusually high response suggested by the supply coefficient at lower levels of total resource use reflects policy actions to withhold area from production. In contrast, the low response indicated at high levels of resource use reflects slowed producer response in an open-market situation. Consequently, many of the coefficients in the over 900 equations of GOL reflect a combination of economic variables as well as policy constraints. Thus, meaningful use and interpretation of output of the model require an understanding of the implications included.

ALTERNATIVES PRESENTED BY THE MODEL

The GOL model has been used both to assist analysis of broad alternative futures and to assist answering specific questions. The broad alternatives usually specify income growth or technological progress as being faster or slower than expected. Or they specify general changes in import restrictions. The broad alternatives are implemented by changing, uniformly, the income or population growth rates for the developed or developing regions and by changing specific model parameters that represent, for example, import levies. Some specific questions for which runs have been developed are these:

- What would happen to production, consumption, and trade if the U.S. export price of grains were fixed?
- What would result if Brazil added substantially to its oilseed area?

Answering such questions often requires adding additional equations and variables to the model, and, usually, careful consideration of the overall model structure.

STATUS OF MODELING EFFORT

The modeling efforts outlined here are in varying stages of development with regard to:

- Testing the mathematical feasibility of quantifying the interaction of economic, technical, and policy considerations.
- Developing computer capabilities to generate and present alternative futures at reasonable costs
- Exploring the issue of short-term forecasts versus long-run projections
- Establishing linkages to other models that have different aggregations and
- Retaining GOL's stochastic properties and assessing the probabilities of alternative futures.

The GOL model moves beyond previous ERS efforts to developing an ongoing detailed world model with several commodities, one sufficiently flexible to project alternative futures that are internally consistent within and between alternatives. The computer program consists of three parts: (1) a matrix generator to facilitate data input, (2) the MPS-3 programming system for obtaining the solution, and (3) a report writer for presenting results.[5]

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[5] Roger Strickland helped develop the matrix generator (*17, 25*). Current costs for the usual run at USDA's Washington Computer Center are about $20 for the matrix generator, $20 for the solution, and $3 for a printout of the results. Output includes about 30 tables containing data on supply and distribution, prices, per capita production and consumption, and growth rates; and special summary tables.

Level of Detail

GOL's main strength is its level of commodity, regional, and price detail. It provides for resource competition across the crop sector and demand competition among different crops for food and feed use. GOL also incorporates physical input-output rates in the feed-livestock sector and in the crop sector of the developing countries. The regional detail differentiates producing and consuming regions as well as regions at different levels of economic growth and income levels. The model's supply, demand, and trade price detail allows policy flexibility on production and marketing strategies. While the detail incorporated into GOL leads to a number of computational problems, exclusion of any of the model's commodity, region, or price components could reduce cross-commodity and cross-region competition and differentiation.

Limitations

A number of programming limitations affect GOL. The endogenous (simultaneous) part of the model is limited to linear equations. At low price levels, such equations tend to generate very low price response. Nonlinearities are handled by specific changes to the input file; that is, by compensating through coefficient adjustments. Also, the current version of the model does not include a trade matrix or an objective function. Though set in a linear programming (LP) framework, GOL has a square matrix, in which the solution algorithm is used as a matrix inverter. A transportation and transfer matrix and objective function could be added at some later date.

GOL is a static equilibrium model. Though this characteristic may be appropriate for long-term projections, it is not satisfactory for short-term and, possibly, intermediate-term forecasting. Equilibrium point estimates can be made for different projected time periods, but estimates for each period are independent of estimates for any other period. A more ideal system would project a dynamic sequence of estimates, beginning from some current level because some variables (such as stock levels and production shortfalls) are critical in the short and intermediate term. Other variables (such as population and those factors affecting the resource base) would predominate in the longer run. The modeling system should permit testing the impact of a disturbance, such as a production shortfall, at any future point in time in relation to the projected situation at the point of disturbance. Work in this area, taking into account trade flows, is being pursued by Takayama in Illinois and, to a lesser extent, by Johnson at North Carolina State. ERS economists, particularly Kost and Schwartz, are also working to link long-range projections with short-term forecasting in the international area.

Future Refinements Under Consideration

Three methods are currently being considered to solve GOL's programming limitations. First, the number of variables could be reduced by combining some regions or by eliminating the "accounting" variables; that is, those variables which appear only in their definitional equations. Second, the GOL model could be taken out of the LP environment, as other solution algorithms may be preferable. Third, pre- and post-optimization routines could be added to the computational system. For example, it might be desirable to divide the model into subsectors, as explained below. This procedure would reduce the number of variables and equations that would be needed for the LP (or quadratic programming) optimization routine.

Another area needing more study is that of linkages with other international models, whether in terms of inputs or outputs. Linkage questions also arise from problems of aggregation or disaggregation. Factors such as income link the GOL model to a country or region's general economy. However, no provision is made for feedback, which could be important in those developing countries where agriculture is the major sector in the economy. A multicommodity model, in some instances, should also be linked to more global trade models to reflect changes in foreign exchange positions and their impacts on commodity trade. Linkage to a more detailed single-commodity model may also be desirable. Also important is tying the GOL model output into the more detailed ERS core projections system for the United States and providing for cross-model interaction. More formal interaction is needed here.

In the current version of GOL, grains were emphasized, and livestock products received less than full coverage. As more information becomes available, particularly for the developing countries, the livestock sector could be enlarged. This change could require creating separate detailed submodels which could be linked to a more aggregate type of GOL model. Subsector models of this type could be integrated into a collapsed version of GOL in which only the excess supply and demand functions (trade) would be solved simultaneously.

Very little formal analysis has been done to evaluate the stochastic properties and assess the probabilities of alternative GOL projections. This work would require assessing the probabilities of the assumptions as well as the stochastic properties of the model structure. Projecting backward into history might provide some clues. However, projections of alternative futures often involve changes in structures that have no historical record. Further analytical effort is needed to document those parts of the model with stochastic properties and those without them, so that the relative probabilities of the projections can be realistically assessed.

WORLD GRAIN-OILSEEDS-LIVESTOCK ECONOMY, 1985: ASSUMPTIONS

Each of the alternative projections of the GOL model has involved general as well as specific assumptions. Several of them, such as the absence both of major wars and natural disasters, are common to all the alternatives. Incorporating a natural disaster or world war assumption would completely overshadow the relationships within the agricultural sector or the general economy, and it would shape projections to fit exogenous political or humanitarian considerations. The areas covered in some of the basic assumptions are outlined below.

General Assumptions

Population. Population growth is a key variant in demand growth for agricultural products. The United Nations median variant population growth rates, as assessed in 1974 and modified within ERS to reflect subsequent developments, were used for each region. An exception was the United States, for which population is projected according to series III figures from the U.S. Department of Commerce. From 1969-71 through 1985, population is expected to increase 0.8 percent annually in the developed world and 2.7 percent annually in the developing market economies.

Income. Income is another key variant in demand growth for agricultural products. While population may be the single most important demand factor in the developing countries, income is the most significant contributor in the developed nations.

USDA projections use real per capita private consumption expenditure (PCE) or, when PCE data are not available, either gross domestic product or net material product as demand shifters. The basic income projections used in GOL are the projected "trend" income values from the Food and Agriculture Organization's (FAO) 1974 *Assessment*. For the developing countries, FAO rates to 1985 are above the trend levels of the last decade and a half. GOL's alternative projections are based largely on adjustments to those basic income growth rates. In all cases, however, income and price inputs are measured in constant currency units with a 1970 base.

Specific Assumptions

Technology and Inputs. The projections assume that technology will continue to evolve as in the recent past. The developed countries, and, to a lesser extent, the developing countries, will continue to take advantage of technological innovations. Rates of adoption, however, will generally remain limited by the relative costs of inputs, particularly the energy costs assumed to be higher for the projected period than in the past decade. More specific adoption assumptions, particularly for the developing countries, are incorporated into individual GOL alternatives.

Some analysts question whether technological improvements will permit increases in crop yields over the next decade and a half at the rates achieved over the last two decades. However, analyses of growth in grain yields in the major grain-producing regions of the world for 1965-75 fail to substantiate the contention that growth in grain yield is stagnating.

Weather Variability and Stock Change. Weather variations and stock levels are key factors affecting supply availabilities, price fluctuations, and trade levels. Production levels in any one year will be affected by long-term weather trends as well as by year-to-year fluctuations. Alternative stock policies aimed at accumulating and drawing down reserves in periods of surplus or production shortfall can either aggravate or minimize the price and consumption adjustments generated by weather fluctuations.

The GOL alternatives all assume normal weather. Small fluctuations in stocks are associated with a normal weather assumption. If weather patterns deviate substantially from the normal of the last two decades, and if shortfalls occur more often than twice a decade, substantially high production levels in the "good" years would be needed to accumulate sufficient stocks to maintain consumption in "bad" years. Given the probability of shortfalls and specific policies as to how much these would be covered from stocks and how much met by cutbacks in consumption, another GOL alternative could be projected to quantify changes in price, production, consumption and trade levels.

Policy Assumptions. The policies of the major importing countries can affect production, consumption, and trade as much as can the interactions of economic variables. Agricultural and trade policy assumptions are incorporated into the different alternatives, explicitly or implicitly, through adjustments in the coefficients. For example, the total area equation for the major exporting countries has a very responsive price coefficient to reflect the effect of open-market forces as well as likely government action to adjust area to changes in foreign and domestic supply and demand conditions.

The price and stock policies of the major exporting countries are basic to all the alternatives.[6] The major exporting countries are expected to continue their present policies of adjusting production levels and of carrying at least the minimum stocks necessary to keep the world in relative balance rather than to permit sizable surpluses and deficits to develop.

The restrictive trade and domestic agricultural production policies of the major developed importing countries other than Japan are expected to continue through 1985 in GOL's base alternatives. The countries of Western Europe in particular are assumed to maintain at least current self-sufficiency rates through continuation or modification of present food and fiber policies. It is assumed, for example, that the EC will continue to use variable levies to control the flow of imports. It is also assumed that price policies of other Western European countries will result in price levels similar to those in the

[6] Given the key U.S. role in either the export or import of all the commodities considered in GOL, the appropriate U.S. c.i.f. or f.o.b. price is used as an indicator of world supply and demand conditions.

Community. Possible changes in policy mixes are tested under different alternatives.

The longrun level of U.S. trade with the USSR, People's Republic of China, and Eastern Europe is assumed to be affected more by political than economic factors. Though no special multicommodity trade agreements have been assumed between the United States and the centrally planned countries, the levels of trade projected are in line with the quantities outlined in recent bilateral agreements.

The livestock and poultry economies starting up in most of the developing countries are not assumed to have taken off by 1985. Foot-and-mouth disease, aftosa, will continue to strongly influence trade patterns. As aftosa already exists in both Europe and South America, trade in fresh and frozen meat between these two continents will continue. And because the disease does not exist in Oceania and the United States, they will be able to export to the whole world, but they will not import fresh or frozen meat from any affected areas.

Quotas on beef imports to the United States are assumed to continue. Imports of dairy products to the United States also continue to be limited by quotas. Butter is excluded and some growth in cheese imports is permitted as demand warrants. Because of continued health regulations, other policy factors, and natural developments, fresh milk is assumed not to be traded. Primary adjustments in dairy markets between countries will occur for butter and cheese. It is assumed that their prices can be read as barometers of price pressures in the international dairy situation.

WORLD GRAIN-OILSEEDS-LIVESTOCK ECONOMY, 1985: RESULTS

Overall Conclusions

The general results common to all alternative sets of 1985 projections from GOL generated to date indicate the following:

- Continued growth in economic activity, particularly in the developed countries, would generate a strong and growing demand for meat and livestock products—under all alternatives.
- Per capita meat consumption grows under all alternatives projected; however, per capita consumption stagnates in the developing countries under the low-income growth alternative.
- In the base projection, per capita meat consumption in the commercial sector of the world meat economy is expected to rise from 72 kilograms to an annual average of 78 kilograms in 1985.
- Though expanding demand for livestock products cannot occur without growth in income, national production and trade policies may be more important than income growth in determining world demand and trade levels for meats. Policies stimulating or dampening meat consumption growth in Western Europe and Japan could alter world trade patterns directly, and they could retard or stimulate meat consumption elsewhere indirectly.
- Continuation of present policies would tend to bring high internal price policies and continued barriers to meat imports in Western Europe and Japan, including restrictions on consumption in some developed countries because of high fuel and energy costs.
- Developed countries will continue to be the major meat producers—almost two-thirds of world meat in 1985.
- In the base projection, a 44-percent increase in feed grain allocation is associated with a 36-percent rise in meat production in the developed countries; in the developing countries grain use for livestock feed grows 79 percent while meat production increases 70 percent.
- Projected higher relative feed costs will dampen expansion of meat production unless economies occur in the marketing and production structure of the livestock sector.
- If harmonization of the European Community is fully realized by 1985, the following impacts on trade patterns in meat follow:
  —The United Kingdom is largely eliminated as an import market for third-country meat as EC members trade more and more with each other.
  —Australia loses the United Kingdom market but enjoys largely offsetting expansion of exports to the United States, Japan, and elsewhere.
  —Argentina's loss of the EC market is not directly compensated in the U.S. market because of the aftosa problem.
- The United States continues to be a more important market than Japan and Western Europe for meat imports; if Japan and Western Europe adopt a less restrictive approach, the traditional exporting countries would find markets more encouraging in Western Europe and Japan than in the United States.
- Over the next decade, the world can produce enough grain at reasonable prices to meet the demand of a largely cereal diet in the developing world and a moderately rising feed demand in the developing world.
- World trends in the production of individual grains are expected to continue. Wheat will account for slightly less than a third of the grain total while coarse grains are expected to increase slightly, at the expense of rice, to roughly three-fifths of the total. Approximately two-thirds of the production increase is expected to result from assumed levels of improved yields. The remaining one-third results from increases in area.
- Importing and exporting countries in the developed and centrally planned countries will continue to be

the major producers and consumers of wheat and coarse grains; rice production and consumption will remain concentrated largely in the developing countries.

- The big factor in the growth in demand for grain in the developed countries will be the feed demand generated by an expanding livestock sector.
- Substantial increases in food grain demand are expected over the next decade in the developing market economies, primarily because of an expected 2.7-percent growth in population. Total cereal consumption is projected to rise annually at 3.2 to 3.7 percent.
- The world grain balance hinges largely on the degree to which the lower income developed countries follow the feed usage patterns of the United States and the European Community. If income grows rapidly in the developing countries and it is translated into demand for livestock products, or if the medium and low-income developed countries adopt the livestock techniques of Japan, the European Community and the United States, or if both developments occur, grain prices would be pushed substantially above the base 1970 price level. But as demand for feed tightens available world grain supplies, food demand would be expected to outbid feed demand, particularly in the developing countries.

Specific Conclusions Regarding the Developing Market Economies

Based on results of GOL for all 1985 projections, certain developments are likely in the developing market economies:

- World grain production over the next decade will permit continued improvement in per capita cereal consumption in the developing market economies. Per capita consumption levels are projected to rise from 172 kilograms in the 1970 base to 185 kilograms in 1985 under the base assumptions. Per capita consumption would be as high as 202 kilograms under the high demand, high productivity alternative.
- Production of cereals in the developing market economies is projected to barely exceed the annual population growth rate of 2.7 percent. Growth in production under the high productivity alternatives, however, would average a full 1 percent above the population growth rate.
- The developing countries' import demand is projected to rise from 18 million metric tons in base period to 48 million tons in 1985 under the base alternatives and as high as 68 million tons under the high-demand alternative. Developing countries' imports could be as small as 34 million tons if these countries accelerate production by increasing inputs and adopting updated technology at the rates postulated under the high productivity alternative.

APPENDIX

Details of GOL Model in 1975

The Appendix summarizes GOL's mathematical form and presents one region's equations (pp. 96-97).

In matrix form, the model can be written as:

$$AX = D$$

where A is a coefficient matrix (square) of linear interactions, X is a vector of endogenous variables, and D is a matrix of the exogenous parts of the model.

Though the matrix A must be linear because a linear programming solution is used, matrix D has no such limitations. The form of D depends on the assumptions made with respect to the kind of impact expected from the exogenous or given variables. The impacts may take one or some combination of the following forms:

$$D = C + B(1 + R)^T$$
$$D = C + EZ$$
$$D = C + KT$$

The first assumes a compound growth rate is appropriate. B is a vector of bases to be compounded, R represents a set of growth rates for particular exogenous variables, and T is the number of years over which compounding occurs. The second form assumes linear growth in which E is the coefficient matrix and Z, a vector of exogenous variables. The third simply assumes that linear trends prevail.

In the equations, the following code is used:

Characters

First, second	country
Third, fourth	functional designations, such as supply and demand
Fifth, sixth	commodity

Demand Equations

$$C6QDB + 2.6972\ C6PDB - 1.6403\ C6PDP + .6907\ C6PDZ = 1{,}448.4 + 4{,}828[1 + .6(.03263) + .00580]^T$$

$$C6QDP - 1.994\ C6PDB + 4.528\ C6PDP - .8590\ C6PDZ = 899.3 + 4{,}997[1 + .5(.03263) + .00580]^T$$

$$C6QDZ - .5814\ C6PDB - 1.0855\ C6PDP + 2.934\ C6PDZ = 363.88 + 1{,}917[1 + 1.0(.03263) + .00580 + .005]^T$$

$$C6QDV - .0276\ C6PDB - .0392\ C6PDP + .0594\ C6PDV = -11.46 + 231[1 + .00580]^T$$

$$C6QDLM + 76.52\ C6PDLM = 7{,}881.6 + 31{,}526[1 + .2(.03263) + .00580]^T$$

$$C6QDLB + 4799\ C6PDLB = 837.91 + 1{,}197[1 + .2(.03263) + .00580]^T$$

$$C6QDLC + .7591\ C6PDLC = 1{,}099.2 + 1{,}832[1 + .5(.03263) + .00580]^T$$

$$C6QDWH + 44.46\ C6PDW = 4{,}460.2 + 22{,}300[1 - .1(.03263) + .00580]^T$$

$$C6QDCH + 21.38\ C6PDC = 1{,}964.8 + 9{,}825[1 + .1(.03263) + .00580]^T$$

$$C6QDRH + .5425\ C6PDR = 181.19 + 604[1 + .2(.03263) + .00580]^T$$

$$C6QDGF - 1.3\ C6QSB - 3.6\ C6QSP - 2.7\ C6QSZ - .25\ C6QSV - .1248\ C6QSL - 3.1\ C6QSE - 30.92\ C6PSP + 253.67\ C6PDC - 45.72\ C6PDK = -51{,}128.84 + 46{,}625[1 + .005]^T$$

$$C6QDWF - .185\ C6QDGF + 20\ C6PDW + 50\ C6PTW - 50\ C6PTC = 2{,}150.28$$

$$C6QDCF + C6QDWF - C6QDGF = 0$$

$$C6QDKF - .16\ C6QSB - .67\ C6QSP - 1.18\ C6QSZ - .0326\ C6QSL - .71\ C6QSE - 17.8\ C6PSP - 103.3\ C6PDC + 25.40\ C6PDK = -30{,}474.74 + 10{,}546[1 + .004]^T$$

Supply Equations

$$C6QSB - 2.27\ C6PSB + .8785\ C6PSP - 6.431\ C6PSL + 9.6104\ C6PDC + 4.3307\ C6PDK = -441.6 + 4{,}416[1 + .02]^T$$

$$C6QSP + 1.952\ C6PSB - 4.698\ C6PSP + 3.098\ C6PSZ + 22.028\ C6PDC + 9.926\ C6PDK = 2{,}530.9 + 5{,}091[1 + .024]^T$$

$$C6QSZ + .494\ C6PSB + .509\ C6PSP - 2.743\ C6PSZ + 8.356\ C6PDC + 5.649\ C6PDK = 768.0 + 1{,}920[1 + .044]^T$$

$$C6QSV + .0376\ C6PSB - .284\ C6PSL + .3183\ C6PDC - .0602\ C6PSV = 165.74$$

$$C6QSE = 2{,}576[1 + .00580]^T$$

$$C6QSL - 8.425\ C6PSB - 252.9\ C6PSL + 404.9\ C6PDC + 218.9\ C6PDK = -3{,}721.96 + 74{,}412[1 + .003]^T$$

$$C6QSLC = 1{,}859[1 + .5(.03263) + .010]^T$$

$$C6QSL - C6QDLM - 22.935\ C6QSLB - 7.105\ C6QSLC = 0$$

$$C6HAT - 29.05\ C6PSC = -2{,}192.7 + 21{,}925[1 - .75(.03263) + .025]^T$$

$$C6HAW - 71.32\ C6PSW + 91.67\ C6PSC - .435\ C6HAT = 347.41 - 80\ T$$

$$C6HAC + 71.32\ C6psw - 91.67\ C6PSC - .530\ C6HAT = -295.035 + 80\ T$$

$$C6HAR - .2157\ C6PSR = -38.791 + 194[1 + .003]^T$$

$$C6QSW - 81.26\ C6PSW - 3.19\ C6HAW = -1.574.99 - 63.07\ C6ZI + 875\ T$$

$$C6QSC - 156.18\ C6PSC - 3.47\ C6HAC = -3{,}932.2 - 78.59\ C6ZI + 1{,}260\ T$$

$$C6QSR - .735\ C6PSR - 3.41\ C6HAR = 65.58 - 1.983\ C6ZI + 6\ T$$

$$C6QSK = 549 + 10\ T$$

Regional Equilibrium Conditions

$$-C6QSB + C6QDB + C6QTB = 0$$

$$-C6QSP + C6QDP + C6QTP = 0$$

$$-C6QSZ + C6QDZ + C6QTZ = 0$$

$$-C6QTZ - C3QTZ = -44.0$$

$$-C6QSV + C6QDV + C6QTV = 0$$

$$-C6QSLM + C6QDLM + C6QTLM = 0$$

Regional Equilibrium Conditions (Continued)

$$- C6QSLB + C6QDLB + C6QTLB = 0$$

$$- C6QSLC + C6QDLC + C6QTLC = 0$$

$$- C6QSW + C6QDWH + C6QDWF + C6QTW = 0$$

$$- C6QSC + C6QDCH + C6QDCF + C6QTC = 0$$

$$- C6QSR + C6QDRH + C6QTR = 0$$

$$- C6QSK + C6QDKF + C6QTK = 0$$

Supply-Demand Price Equations

$$C6PSB - .7\ C6PDB = 100.9 - 200[1 + .2(.03263)]^T$$

$$C6PSP - .8\ C6PDP = 197.6 - 150[1 + .2(.03263)]^T$$

$$C6PSZ - .7\ C6PDZ = 150.7 - 150[1 + .1(.03263)]^T$$

$$C6PSV - C6PDV = 0$$

$$C6PSL - .1324\ C6PSR = - .3\ T$$

$$C6PSW - C6PDW = - 3.30$$

Demand-Supply Price Equations

$$C6PDLM - C6PSL = 0$$

$$C6PDLB - 22.935\ C6PSL = - 616.305$$

$$C6PDLC - 7.105\ C6PSL = 716.185$$

Demand-Trade Price Equations

$$C6PDB - C6PTB - C6PLB = 0 + 209[1 + .3(.03263)]^T$$

$$C6PDP - C6PTP - C6PLP = - 150.0 + 150[1 + .3(.03263)]^T$$

$$C6PDV - 1.2\ C3PTV = 0 + 134.4[1 + .3(.03263)]^T$$

$$C6PDW - C6PTW - C6PLW = - 21.82$$

$$C6PDC - C6PTC - C6PLC = - 5.63 + .3\ T$$

$$C6PDR - C6PTR - C6PLR = 2.64$$

$$C6PDK - C6PTK = 0$$

Price Equations Variable Levy

$$C6PLB + .2\ C6PTB = 159.0 + 249[1 + .3(.03263)]^T$$

$$C6PLP + .2\ C6PTP = 117.2 + 297[1 + .3(.03263)]^T$$

$$C6PLW + .2\ C6PTW = 13.04 + 45[1 + .1(.03263)]^T$$

$$C6PLC + .2\ C6PTC = 12.36 + 29[1 + .1(.03263)]^T$$

$$C6PLR + .2\ C6PTR = 30.91 + 100[1 + .1(.03263)]^T$$

Regional Price Equations

$$C3PDZ - 1.4\ C6PSZ = - 127.4 + 77.4\ DVZ + 3\ T$$

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REFERENCES

(1) Alm, Hans, Jack Duloy, and O. Gullbrandsen. *Agricultural Price and the World Food Economy. Progress Report for FAO.* Rome, Italy, March 1969. Also presented at the FAO Inter-Secretariat Expert Consultation on Projections, Rome, Italy, Dec. 15-19, 1969.

(2) Bawden, D. Lee. *A Spatial Price Equilibrium Model of International Trade. Jour. of Farm Econ.* Vol. 48, pp. 862-874, Nov. 1966.

(3) Bjarnason, H. F. An Economic Analysis of 1980 International Trade in Feed Grains. Unpub. Ph.D. disser., Univ. Wisc., Madison, May 1967.

(4) Blakeslee, Leroy, Earl O. Heady, and Charles F. Framingham. *World Food Production, Demand, and Trade*. Ctr. for Agr. and Rural Dev., Iowa State Univ., Ames, 1973.

(5) Barry, Robert. *Growth Potential of the Beef and Dairy Industries*. Econ. Res. Serv., U.S. Dept. Agr., For. Agr. Econ. Rpt. 97, October 1974.

(6) Boutwell, Wayne, Clark Edwards, Richard Haidacher, Howard Hogg, William E. Kost, J. B. Penn, J. M. Roop, and Leroy Quance. "Comprehensive Forecasting and Projections Models in ERS." *Agr. Econ. Res.*, Vol. 28, No. 2, April 1976.

(7) Economic Research Service. *The World Food Situation and Prospects to 1985*. U.S. Dept. Agr., For. Agr. Econ. Rpt. 98, December 1974.

(8) Economic Research Service. *World Economic Conditions in Relation to Agricultural Trade.* U.S. Dept. Agr., WEC-10, June 1976.

(9) Food and Agricultural Organization of the United Nations. *Assessment of the World Food Situation, Present and Future.* Rome, Italy, 1974.

(10) __________ *A World Price Equilibrium Model.* Committee on Commodity Problems. Food and Agr. Org., Proj. Res. Working Paper No. 3, Rome, Italy, Oct. 11, 1971.

(11) Grant, Warren R., Troy Mullins, and William R. Morrison. *World Rice Study: Disappearance, Production, and Price Relationships Used to Develop the Model.* Econ. Res. Serv., U.S. Dept. Agr., ERS-608, October 1975.

(12) Houck, James P., Mary E. Ryan, and Abraham Subotnik. *Soybeans and Their Products: Markets, Models, and Policy.* Univ. Minn. Press, Minneapolis, Minn., 1972.

(13) Hutchison, John E., James J. Naive, and Sheldon K. Tsu. *World Demand Prospects for Wheat in 1980 with Emphasis on Trade by the Less Developed Countries.* Econ. Res. Serv., U.S. Dept. Agr., For. Agr. Econ. Rpt. 62, July 1970.

(14) Hutchison, John E., Francis S. Urban, and John C. Dunmore. *Argentina: Growth Potential of the Grain and Livestock Sectors*. Econ. Res. Serv., U.S. Dept. Agr., For. Agr. Econ. Rpt. 78, May 1972.

(15) Judge, G. G. and T. Takayama (ed.). *Studies in Economic Planning Over Space and Time.* North-Holland Publishing Co., 1973.

(16) Missiaen, Edmond, and Arthur L. Coffing. *Canada: Growth Potential of the Grain and Livestock Sector*. Econ. Res. Serv., U.S. Dept. Agr., For. Agr. Econ. Rpt. 77, June 1972.

(17) Moriak, T. F., R. P. Strickland, and W. R. Grant. *World Rice Study: A Software Package for Analyzing International Trade.* Econ. Res. Serv., U.S. Dept. Agr., ERS-609, October 1975.

(18) Moe, Lyle E. *World Demand and Supply Prospects for Oilseeds and Oilseed Products in 1980.* Econ. Res. Serv., U.S. Dept. Agr., For. Agr. Econ. Rpt. 71, March 1971.

(19) Regier, Donald W., and O. H. Goolsby. *Growth in World Demand for Feed Grains Related to Meat and Livestock Products and Human Consumption of Grain*. Econ. Res. Serv., U.S. Dept. Agr., For. Agr. Econ. Rpt. 63, July 1970.

(20) Regier, Donald W. *The Livestock Sector and Derived Feed Demand*. Econ. Res. Serv., U.S. Dept. Agr., 1976.

(21) Rojko, Anthony S., *et al. Alternative Futures for Food in the World Grain-Oilseed-Livestock Economy*. Econ. Res. Serv., U.S. Dept. Agr., 1976.

(22) __________ *Organizing Agriculture in the Year 2000.* Food Policy, Vol. 1, No. 3, May 1976.

(23) Rojko, Anthony S., Francis S. Urban, and James J. Naive. *World Demand Prospects for Grain in 1980 with Emphasis on Trade by the Less Developed Countries.* Econ. Res. Serv., U.S. Dept. Agr., For. Agr. Econ. Rpt. 75, December 1971.

(24) Schmitz, Andrew and D. Lee Bawden. *The World Wheat Economy: An Empirical Analysis.* Giannini Foundation Monograph No. 32, Berkeley, Calif., 1973.

(25) Strickland, R. P., Jr., and J. D. Davis. *Interfacing the MPS/360 Linear Programming Routine with Fortran Programs.* Econ. Res. Serv., U.S. Dept. Agr., November 1972.

(26) Takayama, T., and G. G. Judge. *Equilibrium Among Spatially Separated Markets: A Reformation. Econometrica*, Vol. 32, 1964, pp. 510-524.

(27) Takayama, T. *World Food and Energy Modeling; Market-Oriented Approach.* An invited paper presented at the 1975 Las Vegas ORSA/TIMS meeting.

(28) University of California. *A Hungry World: The Challenge to Agriculture*. Univ. Calif. Press, Berkeley, Dec. 1974.