CONCEPTS BEHIND IIASA'S WORLD FOOD AND AGRICULTURE MODEL AND THE NATIONAL MODEL OF THE UNITED STATES

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FOREWORD

Understanding the nature and dimension of the food problem and the policies available to alleviate it has been the focal point of the Food and Agriculture Program at the International Institute for Applied Systems Analysis (IIASA) since the program began in 1977.

The national food systems are highly independent, and yet the major policy options exist at the national level. To explore these policy options, therefore, it is necessary both to develop policy models for national economies and to link them together by trade and by capital transfers. For greater realism the models in this scheme of analysis are being kept descriptive rather than normative. Ultimately, it is proposed to link models of twenty countries, which together account for nearly 80% of such important agricultural attributes as area, production, population, exports and imports.

Michael Abkin, who was the leader of the joint collaborative effort between Michigan State University and the US Department of Agriculture's Economic Research Service to develop a US model, presents in this paper a brief outline of the concepts behind the FAP system and the national model of the US. He recently left Michigan State University to start up his own consulting firm in California.

K.S. Parikh
Program Leader
Food and Agriculture Program

CONCEPTS BEHIND IIASA'S WORLD FOOD AND AGRICULTURE MODEL AND THE NATIONAL MODEL OF THE UNITED STATES

Michael H. Abkin*

INTRODUCTION

For the past several years, Michigan State University's Department of Agricultural Economics and, more recently, the U.S. Department of Agriculture's Economic Research Service have been collaborating with the Food and Agriculture Program of the International Institute for Applied Systems Analysis (IIASA/FAP) on the development of policy simulation models of U.S. food and agriculture as part of the IIASA/FAP global food and agriculture trade model. With this experience in mind, the objective of this paper is to summarize the concepts underlying the FAP model.

The paper begins with a brief discussion of the background and objectives of the project from both the IIASA/FAP perspective and the MSU and USDA perspectives. An overview of the FAP model system is then presented, including descriptions of its general characteristics, the algorithms used to solve national and global equilibria, and the basic linked system and detailed country models.

BACKGROUND AND OBJECTIVES

IIASA/FAP Problem Setting and Objectives

The Food and Agriculture Program began at IIASA in 1976 motivated by the following perceptions (excerpted from Parikh [1981]:

(a) Large numbers of people go hungry in the world today, although globally adequate food is available. This is true even in nations with adequate food on the average, because of improper distribution of income and food. (pg. 3)

(b) National policies are the important policies in dealing with the problem of hunger, either through increased production and/or through more equitable distribution. (pg. 8).

(c) Though national governments are the highest decision making bodies in the world, the interdependence of nations is critical in determining many national policy options. Trade in food and agricultural products forms a sizeable part of the total trade of many countries, and these countries are affected by the policies of other countries. (pg. 11)

*Consultant, Letter Perfect Systems, 104 Calle Nivel, Los Gatos, California 95030. This is a revised version of a paper prepared for presentation at the North American Conference on Forest Sector Models, Williamsburg, VA, December 2-4, 1981. The work reported herein is partially supported by Cooperative Agreement No. 58-3J22-0-00245 between Michigan State University and the U.S. Department of Agriculture.

(d) The inherent uncertainty in agricultural production implies that even normally self-sufficient countries may need to depend on trade in exceptional years. (pg. 15)

(e) The agricultural sector is embedded in the national economy and should be treated in that setting. In most countries food and agricultural policies dominate economic policies, since food prices affect everyone in the economy. (pg. 16)

The conclusion drawn from these perceptions was that:

> . . . the present food problem is a problem of inadequate food consumption by a large number of people as a result of insufficient income and improper distribution, which is accentuated by uncertain climatic conditions, and which is amenable mainly to national policies, which are constrained by the actions of other countries. Thus the food and agriculture system of the world is best viewed as set of <u>national</u> agriculture systems <u>embedded</u> in national economies <u>affected</u> by national governments' policies and <u>interacting</u> with each other. [Parikh, pg. 16]

Therefore, FAP's objectives are to (a) identify and evaluate the nature and dimensions of the world food problematique and the factors affecting it, and (b) suggest national and international policies to alleviate current food problems and to prevent future ones in both the intermediate and long runs. The analytical approach taken to achieve these objectives is development and use of a global general equilibrium simulation model composed of national models which interact with one another and respond to various government policy instruments and international agreements. The approach and models are described in a later section of this paper.

MSU and USDA Participation and Objectives

Michigan State University and the U.S. Department of Agriculture are motivated in this effort by similar perceptions from a U.S. perspective. It is clear from the experiences of the decade of the seventies that U.S. agriculture has become intimately tied to the world food and agriculture system and is likely to remain so for the foreseeable future. Policy actions and technological changes occurring in the U.S., whether domestically oriented or trade oriented, can have significant impact on other countries. Similarly, events occurring in other countries with respect to food supply and demand can greatly influence the prices facing U.S. farmers and hence the well-being of the farm sector. Therefore, policy analysis in the U.S. should endogenize these global interdependencies.

Furthermore, recent debates concerning long-term resource constraints, land and water degradation and loss, and the direction that changes in farm structure are taking or should be taking are all testimony to the conviction that short-run forecasting and policy analysis are not sufficient for today's decisionmaking. That is, intermediate- and long-run views are also necessary to address the relevant policy issues.

Finally, the interdependencies between the agricultural and nonagricultural sectors in the U.S. are strong enough that, for longer-run analyses, ignoring them would miss a significant component of direct and indirect policy impacts. Included in these interactions are, for example, the price and availability of fuels, fertilizers, machinery and other agricultural inputs; the intersectoral competition for land, labor, and capital; and agriculture's important contribution to the U.S. trade balance and, therefore, overall national fiscal and monetary health.

IIASA/FAP's global general equilibrium approach offers the means by which U.S. food and agriculture policy analysis can be placed in the necessary international, intersectoral, and long-run context. Furthermore, the algorithms and overall model concept of the IIASA/FAP system are considered to be at the leading edge of the state of the art in this regard. Hence, the objectives of the MSU and USDA cooperative research are to (1) develop a detailed U.S. food and agriculture model which will a) be linkable to the IIASA/FAP system, and b) address the policy issues of interest to the relevant clientele groups in the USDA, elsewhere in the federal government, in state and local governments, in the research community, and in the private sector; and (2) transfer the IIASA/FAP basic linked system -- including country models with the trade linkage algorithms -- to the USDA for installation at the Washington Computer Center for use in projections and policy analysis.

THE FAP MODEL SYSTEM

This section presents an overview of the FAP model system, including discussions of the general equilibrium approach, the basic linked system and the international and domestic equilibrium algorithms. Equally as important to the success of the FAP approach as the technical aspects of the model is the structure of the project and its institutional relationships among country modelers and policymakers with FAP at the center. I will try to give a flavor of this in the discussion of the basic linked system.

General Equilibrium Approach

There are three concepts embodied in the "general equilibrium approach." First, it is general in that the system is closed with respect to countries, commodities, and money. That is, the whole world is modeled explicitly, as are all commodities and money. In this way, there are no infinite sources or sinks of goods and money to absorb policy impacts and mask feedback and other secondary effects.

The country and commodity definitions were selected in order to address the problem context described in the previous section. The specific countries and, in the case of the EC and the CMEA, country groups include the major food importing and exporting countries and were initially selected to cover about 80% of the world's population, land area, and production, exports, and imports of food [Table 1]. Additional countries may be and indeed have been, added to the system depending on interest expressed by persons or groups within those countries. Closing the system, an aggregate rest-of-the-world model is included to endogenize the supply and demand of countries not specifically modeled (i.e., the other 20% of the world).

Two alternative commodity lists are considered in the model (Table 2). The detailed list includes explicity those commodities of primary concern in the world food problem and other commodities and commodity groups of importance to particular classes of countries. Again, the system is closed with an aggregate nonagricultural commodity. The aggregate commodity list was defined to simplify initial model building and testing at IIASA of the basic linked system (described in the next section). Although it is still the operative list for the current version of the model, it is much too aggregated to exploit the full potential of the IIASA/FAP system for policy analysis. Therefore, it is of high priority that the detailed list be implemented as soon as possible.

Even the detailed list, however, may not be detailed enough for some countries' purposes. Thus, although the international equilibrium, and therefore prices, will be determined at the level of one or the other of the lists in Table 2, a country model may be defined at a finer level of commodity detail. For example, Tables 3 and 4 show the definitions used in the detailed U.S. model for supply and demand commodities, respectively.

Secondly, the concept of equilibrium in the "general equilibrium approach" simply is that physical and monetary quantities must balance over the world for internal consistency. That is, in each year, net excess demand for each commodity, summed up over all countries, must be less than or equal to zero for a unique set of nonnegative world prices. In addition, the world price of a commodity is zero when net excess demand for that commodity is less than zero (free disposal) and positive when net excess demand is zero. Furthermore, when this is true, then the world is also in monetary balance, with country trade balances adding up to zero.

It is in reaching equilibrium that the country components of the IIASA/FAP global system interact, as illustrated in Figure 1 for a four-country world. Each country is conceived to be composed of three basic components: (1) a production component, which depends only on government plans and policies, lagged prices, and resource, environmental and technological changes; (2) an exchange component, which encompasses all parts of the country model (primarily demand and income accounting) that are determined simultaneously with prices, given supplies and government policies; and (3) a government component which adjusts plans and policies over time in response to socioeconomic conditions and changes taking place in the model. Those parts of supply which depend on concurrent prices -- such as nonagricultural and livestock commodities in the U.S. model -- are also considered to be in the exchange component.

Table 1
Countries in the IIASA/FAP System

1976
PERCENTAGES OF WORLD TOTAL

	POPULATION	PRODUCTION	LAND	IMPORT	EXPORT
USA	5.3	12.3	9.8	8.07	18.85
AUSTRALIA	0.3	1.6	1.3	0.25	5.00
NEW ZEALAND	0.1	0.5	0.1	0.14	2.09
CANADA	0.6	1.2	2.0	1.99	3.25
EC	6.4	11.9	3.3	38.83	25.05
JAPAN	2.8	1.8	0.4	8.35	0.05
AUSTRIA	0.2	0.4	0.1	0.62	0.31
SWEDEN	0.2	0.3	0.2	1.13	0.42
CMEA	9.0	16.7	17.5	12.72	5.74
SUBTOTAL	24.9	46.7	34.7	72.11	61.76
PAKISTAN	1.8	0.9	1.4	0.34	0.34
CHINA	21.4	13.2	17.3	1.64	1.81
NIGERIA	1.6	0.5	1.6	0.50	0.40
ARGENTINA	0.6	2.0	1.7	0.14	2.86
INDONESIA	3.4	1.6	1.5	0.64	1.02
MEXICO	1.5	1.5	1.3	0.35	0.82
THAILAND	1.0	1.1	1.1	0.18	1.23
BRASIL	2.8	4.7	4.8	0.75	5.55
BANGLADESH	1.9	0.7	1.1	0.34	0.11
EGYPT	1.0	0.7	0.3	0.94	0.56
INDIA	15.5	6.7	14.6	1.06	1.30
KENYA	0.3	0.2	0.2	0.06	0.33
SUBTOTAL	52.8	33.8	46.1	6.94	16.33
TOTAL	77.7	80.5	80.8	79.05	78.09

Source: Parikh [1981], pg. 27.

Table 2

IIASA/FAP Trade Commodities

Aggregate Version	Detailed Version
1. Wheat (th. MT, grain eq.)	1. Wheat (th. MT, grain eq.)
2. Rice (th. MT, milled)	2. Rice (th. MT, milled)
3. Coarse grains (th. MT)	3. Coarse grains (th. MT)
4. Bovine and ovine meats (th. MT, carcass)	4. Fats and oils (th. MT, oil eq.)
5. Dairy products (th. MT, fresh eq.)	5. Protein feeds (th. MT, protein eq.)
6. Other meats (th. MT, protein eq.)	6. Sugar and products (th. MT, refined eq.)
7. Protein feeds (th. MT, protein eq.)	7. Bovine and ovine meats (th. MT, carcass)
8. Other foods (mi. $, 1969-71)	8. Pork (th. MT, carcass)
9. Nonfood agriculture (mi. $, 1969-71)	9. Poultry and eggs (th. MT, protein eq.)
10. Nonagriculture (mi. $, 1969-71)	10. Dairy products (th. MT, fresh eq.)
	11. Vegetables (mi. $, 1969-71)
	12. Fruits and nuts (mi. $, 1969-71)
	13. Fish (th. MT, protein eq.)
	14. Coffee (th. MT, bean eq.)
	15. Cocoa and tea (mi. $, 1969-71)
	16. Alcoholic beverages (mi. $, 1969-71)
	17. Clothing fibers (mi. $, 1969-71)
	18. Other nonfood agriculture (mi. $, 1969-71)
	19. Nonagriculture (mi. $, 1969-71)

Source: Abkin [1981], pg. 4.

Table 3

U.S. Model Supply Commodities

1. Wheat (th. MT)
2. Rice (th. MT, milled)
3. Corn (th. MT)
4. Grain sorghum (th. MT)
5. Oats (th. MT)
6. Barley (th. MT)
7. Rye (th. MT)
8. Soybeans (th. MT)
9. Peanuts (th. MT, shelled)
10. Sunflower (th. MT, seeds)
11. Flaxseed (th. MT, seeds)
12. Cottonseed (th. MT, seeds)
13. Cotton (th. MT)
14. Sugar cane (th. MT, refined)
15. Sugar beets (th. MT, refined)
16. Irish potatoes (th. MT)
17. Sweet potatoes (th. MT)
18. Dry beans and peas (th. MT)
19. Other vegetables & melons (th. MT)
20. Citrus fruits (th. MT)
21. Noncitrus fruits & nuts (th. MT)
22. Tobacco (th. MT, farm sales wt.)
23. Coffee (th. MT, beans)
24. Wool (th. MT)
25. Beef & veal (th. MT, carcass)
26. Lamb & mutton (th. MT, carcass)
27. Pork (th. MT, carcass)
28. Chicken (th. MT, ready-to-cook)
29. Turkey (th. MT, ready-to-cook)
30. Eggs (th. MT)
31. Milk (th. MT, fresh)
32. Fish (th. MT)
33. Nonagriculture (mi. $, 1972)

Source: Abkin [1981], pg. 5.

Table 4

U.S. Model Demand Commodities

1. Wheat (th. MT, grain eq.)
2. Rice (th. MT, milled)
3. Corn (th. MT)
4. Other grains (th. MT)
5. Soybeans (th. MT)
6. Peanuts & tree nuts (th. MT)
7. Fats & oils (th. MT, oil eq.)
8. Protein feeds (th. MT, soymeal eq.)
9. Sugar (th. MT, refined)
10. Other sweetners (th. MT, refined eq.)
11. Potatoes (th. MT)
12. Dry beans & peas (th. MT)
13. Fresh vegetables (th. MT)
14. Processed vegetables (th. MT)
15. Citrus fruits (th. MT, fresh eq.)
16. Noncitrus fruits (th. MT, fresh eq.)
17. Beef & veal (th. MT, carcass)
18. Lamb & mutton (th. MT, carcass)
19. Pork (th. MT, carcass)
20. Poultry (th. MT, ready-to-cook)
21. Eggs (th. MT)
22. Fresh milk (th. MT)
23. Cheese (th. MT)
24. Butter (th. MT)
25. Other dairy (th. MT)
26. Fish (th. MT)
27. Coffee (th. MT, beans)
28. Cocoa & tea (th. MT)
29. Alcoholic beverages (mi. liters)
30. Cotton (th. MT)
31. Wool (th. MT)
32. Tobacco (th. MT, leaf eq.)
33. Durables (mi. $, 1972)
34. Services (mi. $, 1972)
35. Other nonagriculture (mi. $, 1972)

Source: Abkin [1981], pg. 6.

It is the exchange components of the national models that are all solved simultaneously (as indicated by the dotted lines in Figure 1) to determine world and domestic equilibrium prices and quantities.

Finally, while the concept of "general equilibrium" is relatively simple, the approach is certainly not. Since there are no unaccounted for sources and sinks in the model to take up any slack, rigid adherence to a complex set of economic conditions and mathematical theorems -- collectively called general equilibrium theory -- is essential for logical consistency. These have all been elegantly developed, complete with rigorous mathematical proofs, for the IIASA/FAP system (Keyzer, 1981), resulting in a "minimal" set of common characteristics each country model must possess in order to be linkable through the international equilibrium algorithm (described below). These linkage requirements include:

1) the country's net excess demand for each commodity must be a continuous function of, and homogeneous of degree zero in, world prices and money (although, since quota constraints are allowed, the first derivatives do not have to be continuous);

2) a common list of commodities and units of measure [Table 2] must be adopted, at least at the country's interface with the world; and

3) an annual time increment must be used.

An additional requirement, a result of the algorithm used rather than of economic theory, is that:

4) each country model must be such that an analytical (not numerical) Jacobian matrix of partial derivatives of net excess demand for each commodity with respect to each world price can be computed.

The algorithms used to implement this approach are described next, followed by a definition and discussion of the basic linked system.

Equilibrium Algorithms

As discussed above, the exchange components of all countries are solved simultaneously each year to find the global, or general, equilibrium. Nested, or hierarchical, iterative algorithms are used in this task, where the international algorithm is at the top of the hierarchy (the outermost iteration loop) and the domestic algorithm is at the bottom (the inner loop). Each of these will be briefly described here verbally to give a flavor of how the system works. Rigorous theoretical and mathematical derivations and specifications are given in Keyzer [1981, Chapters IV and VI].

International equilibrium. A coarse flow chart of the algorithm to achieve international equilibrium is given in Figure 2. Once the exchange component has been entered in a given year, world prices are set to their previous year's equilibrium value to start the iterations. Then, international transfer policies for the current year are set.

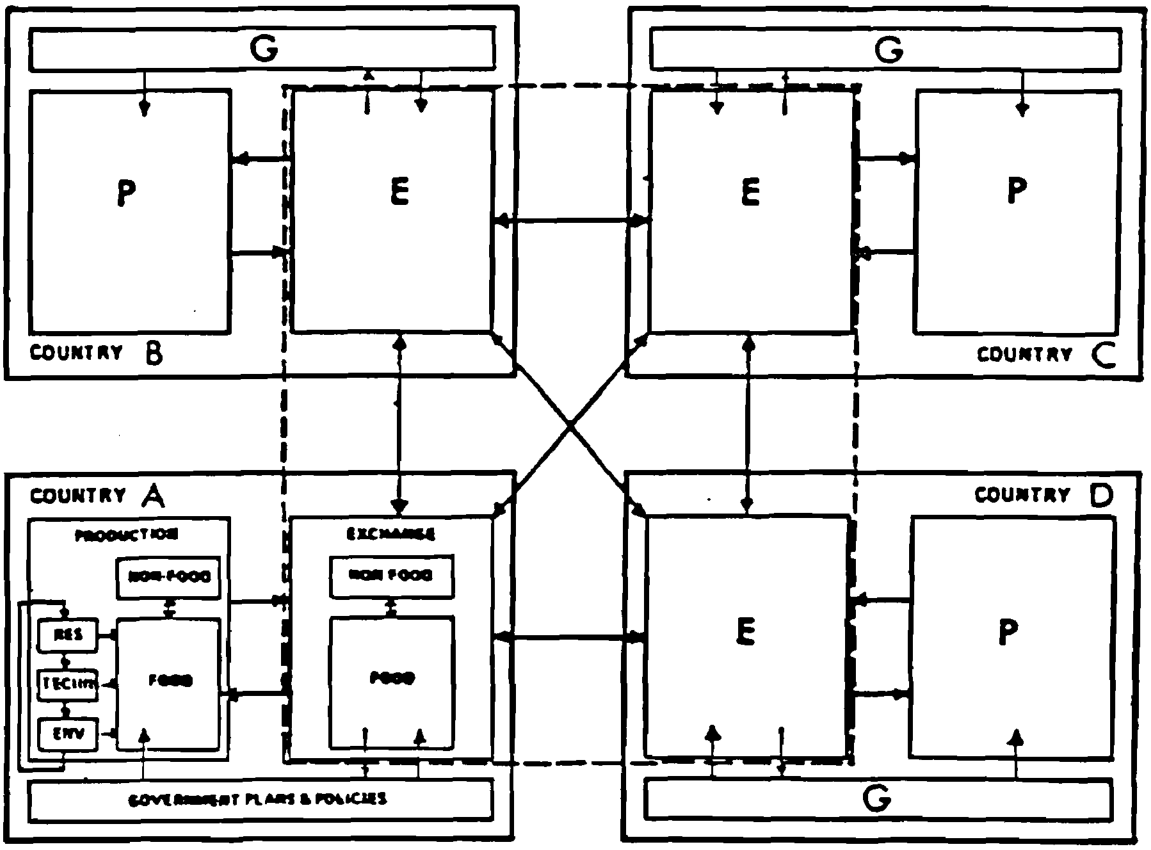


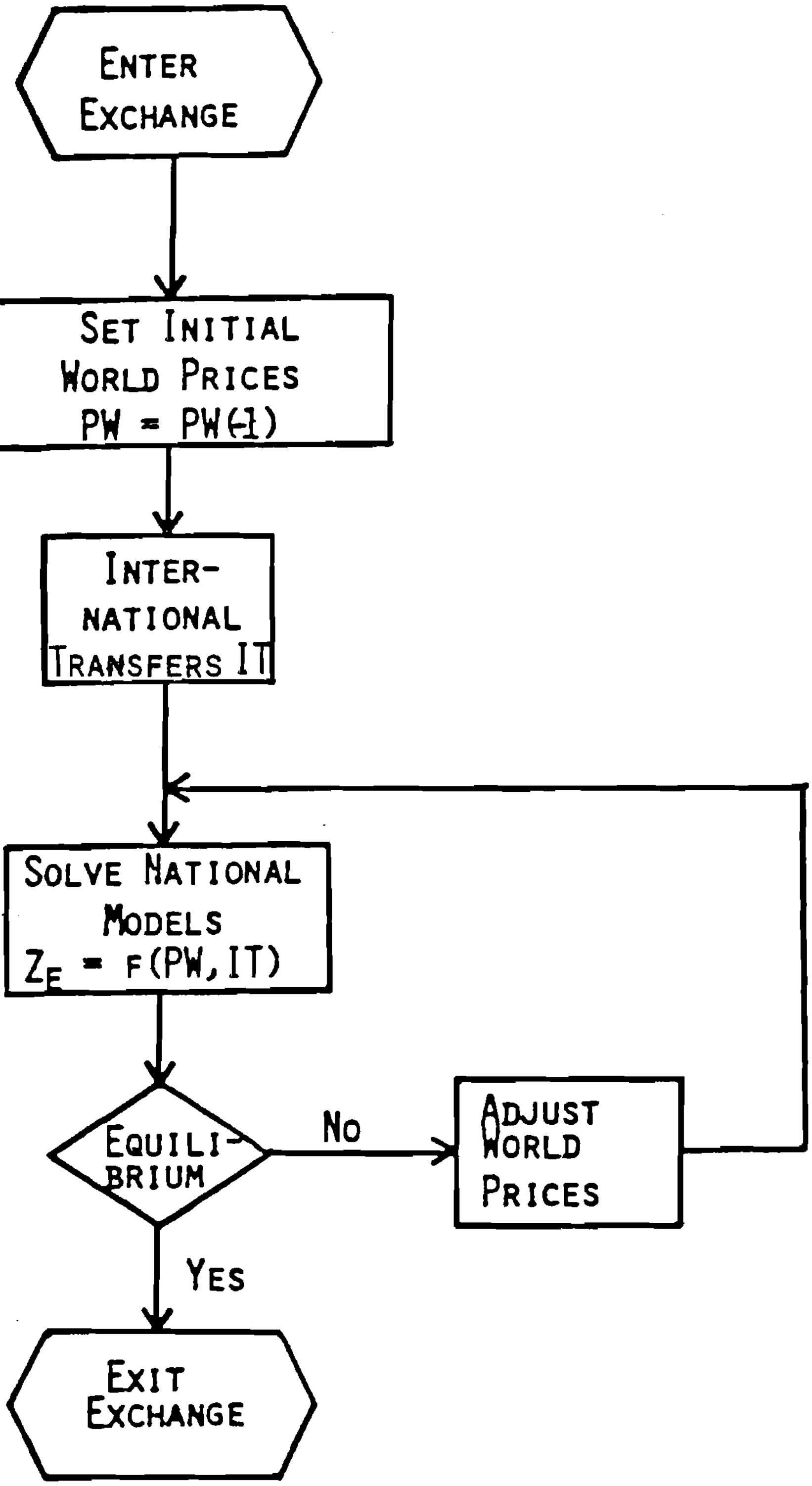
Figure 1

IIASA/FAP International Linkage

Source: Rabar [1979], pg. 8.

Figure 2

International Equilibrium



These are decisions made outside of the exchange equilibrium, i.e., they do not depend on prices in the current year. Such international transfer policies as bilateral or multilateral trade agreements and capital transfers may be considered. In addition to international transfers, which are determined outside the exchange equilibrium, other international policies modeled within the exchange component include buffer stock agreements, external price agreements, and market segmentation. Next, the exchange component of each of the national models is solved in turn for its own domestic equilibrium net excess demand as a function of world prices and international policies. If all the domestic equilibrium net excess demands are consistent with world equilibrium, i.e., they all add up to zero at positive world prices, then the algorithm exits to solve the supply side of the country models for the next year. Otherwise, world prices are iteratively adjusted and the national models solved again until world equilibrium is reached.

The world price adjustments are made with the use of a nonsmooth optimization (gradient search) algorithm [Keyzer, Lemarechal, and Mifflin, 1978; Lemarechal, 1978]. This algorithm is important because, while the excess demand functions must be continuous, their first derivatives may have discontinuities (i.e., the functions are nonsmooth), thus allowing for the use of quota policies.

Domestic equilibrium. The exchange component of each country model is solved at each iteration on world prices. The complementarity path algorithm described here (Figure 3) was developed by Keyzer [1981, Chapter IV] for the standard FAP models and used by most of the country models, including the U.S. Actually any algorithm may be used as long as convergence can be proved, the consistency linkage requirements are met, and the matrix of partial derivatives is computed.

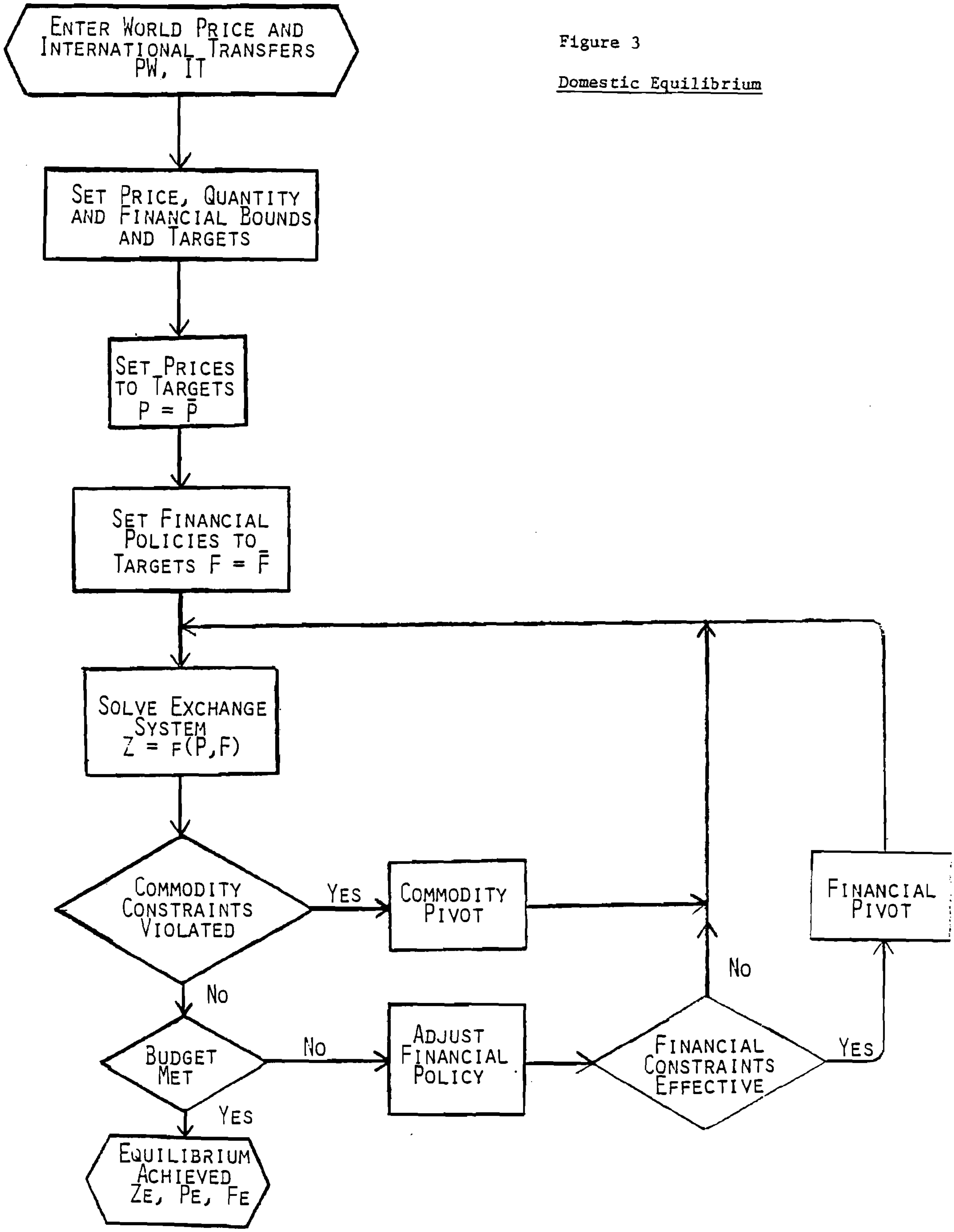
First, any bounds which may be specified are set on domestic prices, buffer stocks, trade, and financial policies. These variables are also set to their target values to start the algorithm. These bounds and targets may be exogenously specified (either from outside the model or based on lagged conditions) or be computed as functions of world prices.

The concept of price "targets" may be interpreted as actual policy targets or merely as a "normal" relationship between domestic and world prices, including any tariffs or subsidies. In any case, however it may be interpreted, these target prices will turn out to be the domestic equilibrium prices if no quantity constraints are effective.

With prices and financial policies (tax rates, public consumption, and trade balance) set to target values, the supply-demand exchange system is solved. If any commodity constraints (price, quota, or stock) are violated, the system is inverted ("commodity pivot") for those commodities to solve for prices which will put the associated quantities at their constraint values. When all commodity constraints are satisfied, and if the national budget is met, the domestic euqilibrium has been achieved in terms of equilibrium prices, financial policies, and net excess demands.

Figure 3

Domestic Equilibrium



If the budget is not satisified, financial policies are adjusted to achieve that end. These adjustment are made in a hierarchical fashion, where lower priority policies are adjusted first and higher priority policies are adjusted only if lower priority ones have reached a bound ("financial pivot"). The priority ranking, targets, and bounds on tax rates, public consumption, and the trade balance are specified as policy parameters by the user exogenously or as functions of lagged conditions in the model. If the balance of trade is being adjusted, this implies that there is no national budget target to be met and, therefore, only one iteration of the financial policy adjustment loop is necessary to reach equilibrium.

Basic Linked System and Participating Institutions

In IIASA/FAP parlance, the "basic linked system" is the international linkage mechanism (i.e., the world superstructure) together with the set of basic country models which plug into that superstructure.

There may be up to two models of a country -- a basic model and a detailed model. All countries specifically included in the system have at least a basic model. A country's detailed model will tend to be more disaggregated with respect to, for example, commodities, regions, income classes, policy instruments, resources, technology, etc., as appropriate for that country. In using the system for a particular analysis, then -- such as bilateral or multilateral agreements among particular countries, or impacts of one country's policies on particular other countries -- the detailed models of only those countries of direct concern need be used, with use of the basic (generally simpler) models of other countries being sufficient for the task at hand.

There are two or three types of basic country models. FAP itself developed a prototypical country model whose common structure has been replicated for most of the FAP countries, with parameter estimates for each country derived primarily from FAO data [Fischer and Frohberg, 1980]. These models are called "standard FAP country models" and comprise most of the basic models in the system. For a few countries, country modelers have developed their own basic models. In some cases, these have used the FAP standard model as a point of departure, eventually replacing it. In others, as MSU has done for the U.S. basic model, a model of intermediate complexity has been developed both to serve as a basic model and to gain experience before tackling the detailed model. In one case, that of India, the detailed model is also used as the basic model.

A vital facet of the IIASA/FAP approach is the creation of a network of participating institutions all over the world developing models of their countries which will all be mutually consistent and executable on a computer for joint analyses. In this regard, FAP's standard basic models have proven very effective in orienting new country modelers to the project, the modeling approach, and the linkage requirements. That is, new groups may begin their participation by first examining the structure and evaluating the operation of the FAP standard model for their country. They may then reestimate it using their own country's data rather than FAO's and possibly make other modifications, resulting in an improved basic model for that country -- at least improved in the eyes of interested parties in that country, which is important for the international cooperation among researchers, analysts, and policymakers necessary for the FAP objectives to be ultimately achieved. Once familiarity with, and some degree of confidence in, the structure and requirements of the IIASA/FAP system have been thus attained, participating groups may then proceed to the development of detailed country models.

Another aspect of the distinction between basic and detailed country models emerges in the FAP policy statement on the distribution and use of the system. That is, participating institutions, such as MSU and USDA in the U.S., are entitled to receive copies of updated versions of the basic linked system, including the linkage superstructure, the set of basic country models, and associated data files, in return for updated versions of the basic or detailed model developed by the institution. The public version of the detailed country models residing at IIASA are not to be distributed automatically to other participating institutions, as is the basic linked system, but are to be used at IIASA for joint analyses, with further distribution at the discretion of the participating institutions supplying them.

CONCLUSIONS

The FAP model system is currently operational on the VAX computer at IIASA, and a copy of it is in the process of being transfered to the CDC and IBM computers at MSU and USDA. The system was used recently for a study IIASA/FAP did for the OECD. This is not to say the system is "final". No model, if it is to remain relevant and useful, can be considered final or complete. In the case of FAP, the IIASA team has its work cut out for it not only to maintain and use the model system but also to continue to extend and improve it in a number of important ways (such as disaggregation to the detailed commodity list of Table 2, mentioned earlier) and to maintain and expand the international network of participating institutions it has created.

The concepts behind the FAP model system have a great deal to offer those interested in modeling and analyzing other sectors, such as is being considered by IIASA for the forestry sector. From the FAP perspective, application to other sectors would represent a much-needed disaggregation of the nonagricultural commodity. For forestry purposes, too, it may be desirable to further break down nonagriculture to consider important inputs, processing, and substitute sectors. It may also be necessary to consider some disaggregation of agriculture — although probably not at the levels indicated in Table 2 -- to capture the important interactions between forestry and agriculture. In any case, the FAP approach can be usefully applied to forestry or any other sector where international trade is important and where national policies should be analyzed in a general equilibrium framework so as not to miss important feedback and other indirect impacts.

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