

Global Modelling of Food and Agriculture

CENTRE FOR WORLD FOOD STUDIES*

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The Centre for World Food Studies is developing price endogenous models focusing on agriculture and incorporating detailed agronomic information. Moreover, the structure of these models is such that they can be linked in order to represent international trade, resulting in a global equilibrium. The developing country models emphasize and analyze the problem of small and landless farmers, the role of possible ecological constraints, and the changes in the distribution of income between agriculture and non-agriculture as well as within agriculture. Model alternatives can be analyzed through changes in various parameters, e.g. direct and indirect tax rates, tariffs, buffer stocks, import and export quotas. A brief outline of the Thailand model is presented.

I. INTRODUCTION

National and international modelling concerning food and agriculture has been the focus of research undertaken at the Free University in Amsterdam and the Agricultural University in Wageningen since late 1972. The issue of meeting basic food needs had been raised earlier in discussions which followed the studies on global long-term perspectives commissioned by the Club of Rome. After the publication of the pessimistic views derived from these studies, the question arose whether possible sets of policies could be suggested to improve the prospects for mankind, at least by meeting some of the basic needs of the world population in the early years of the next century.

The research group completed the first phase of its work in 1976. The findings were published in "MOIRA: A Model of International Relation in Agriculture" (1979); well before that time, the main findings had been published in summary format and were presented at international gatherings. The character of the research effort as a multidisciplinary undertaking and the methodological nature of the exercise did lead to a second phase of the work; originally this had not been foreseen but

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in the course of the exercise it became clear that some promising avenues for further research were opening up. This did lead directly to the establishment of the Centre for World Food Studies in early 1977 and contributed to the initiation of a Food and Agriculture Program (FAP) at the International Institute for Applied Systems Analysis (IIASA) in Laxenburg (Austria) around the same time.

The Centre is not by any means the only institution engaged in this exercise. The Food and Agriculture Program at IIASA is the main centre of work on the international model as well as on an increasing number of national ones. The latter are being undertaken by research institutes in participating countries, covering by now most of the developed countries and also a fair number of developing ones. In addition, IIASA has put an international model to the test by taking the lead in constructing a series of simplified national models for linkage purposes.

The contribution of the Centre to the IIASA programme consists of several elements, some of which go beyond the contributions of the other participating national research institutes. The Centre has particularly contributed to the formulation of the main characteristics of the national models: their design as equilibrium models and their requirements for linkage to the international model. In addition, it has contributed to the formulation of the international model. Thirdly, the agronomic-economic approach to country modelling is up till the present a unique feature of the Centre's work. The latter component is increasingly receiving international attention and may in due course be adopted also in some form for the IIASA programme.

II. THE ECONOMIC MODEL COMPONENT¹

Basic Considerations

The widespread occurrence of hunger in the world at present and the chances that hunger will affect increasing numbers of people are generally recognized as global issues. This view is supported by the moral argument that human deprivation should not be tolerated side by side with abundance and waste of food in parts of the world, in particular when natural and technological resources appear adequate to meet the food needs of all mankind. Support stems also from economic arguments which emphasize the growing interdependence of national food systems through international markets and prices.

Hunger is in the first place a *local* phenomenon, determined by a variety of factors amongst which physical, economic, social and demographic ones are predominant. But the extent and degree of hunger can be influenced by interactions between countries. Conversely, solutions to local hunger are bound to influence the pattern of interaction between countries. The analysis of the global food situation

¹This section is based mainly on [1] and [2].

and its prospects therefore must specify the local structures in which the problem arises and also map out the interaction of those structures. This observation is basic to the structure of the modelling system.

Local hunger problems stem from the interaction of factors at the local (particularly the national) level. The mechanisms which generate these local situations and determine their behaviour over time must therefore be identified. Therefore, the objective is to develop a set of models presenting national agricultural systems which are embedded in national economies interacting with each other. Country models have a key role in the system, recognizing the national control over resources and their uses and the role of national government policies. The interaction between countries is recognized as complex, as local and global changes mutually condition each other.

The extent of hunger and malnutrition in a country does not depend only on the level of total national food supplies but also on their distribution. The factors which determine this distribution are complex and not well understood, but can be distinguished roughly between the ones describing the ownership structure of (particularly scarce) factors of production and those representing the effects of government policies. A substantial part of hunger appears to occur in rural areas where people are mainly dependent on agricultural activities to earn their livelihood. This suggests that the analysis of hunger must take account of the distribution of control over land and of access to inputs and services. Similarly, the operation of rural labour markets and the causes and effects of labour migration need to be taken into account. Government policies can address themselves to changes in control structures (land reform, education policies, for example) or to change income and/or food distribution directly through transfer systems between population groups. These considerations constitute the basic premises for the formulation of the national model.

The national models – which are developed independently by country experts – should be linkable into one global model and should therefore meet basic linkage requirements. Thus, international trade variables should follow a common commodity classification (i.e. 18 agricultural and 1 residual non-agricultural commodities). Imports and exports are to be generated on an annual basis. Further, imports and exports should be functions of world market prices which are insensitive to the absolute level of prices.

The national models are labelled *open exchange models*: “open” because there is international trade, “exchange” because a one-period lag in supply is assumed. *Competitive international equilibrium* is one of the modes for interlinking a system of open exchange models; an *international buffer stock agreement* and a *market segmentation agreement* offer alternative modes. The economic process is modelled by first describing the behaviour of individual agents (producer, consumer, government) and then integrating this behaviour through the imposition of overall physical and financial balance equations, in the Walrasian equilibrium tradition.

Each national model consists of the following components:

- (a) supply,
- (b) demand,
- (c) income and price formation, and
- (d) national government policies.

Each national model is an actor in the international model, and *international government policies* influence its operation. The formulation of these model components for a specific national model raises general methodological issues. Some of these issues have already been dealt with by the Centre, others are planned to be studied in the near future. They will be discussed below in more detail but first three general issues require to be resolved in advance as they pertain to the modelling exercise as a whole:

- (1) *Commodity Breakdown*: which commodities should be distinguished in the model; how many agricultural, how many non-agricultural, how many factors of production?
- (2) *Data Collection and Processing*: establishment of the format of an internally consistent data bank.
- (3) *Computation*: the design of algorithms which enable one to numerically solve the model.

As the next step, the following issues can be raised with respect to individual model components.

Supply

- (a) The way in which to represent technological relations and to obtain estimates of technical parameters; and
- (b) The approach to describing producers' behaviour and the interaction between producers (e.g. small vs. large farmers).

Demand

The description, by income group, of consumer demand as functions of prices and incomes, which adequately describe both short and long term substitution effects between commodities and generate realistic nutritional intakes under changing incomes and prices.

Income and Price Formation

- (a) The description of income transfers among income groups and between government and income groups; and
- (b) The determination of the factors which cause price distortions in the domestic market, e.g. by relating changes in retail prices to changes in farm gate prices.

National Government Policies

- (a) The description, in a simplified and generalized way, of government practices in a country in order to obtain the main characteristics of the country's legislation; and
- (b) The quantification of the postulated relations.

International Government Policies

- (a) The description of existing international arrangements in quantitative terms; and
- (b) The design of new international agreements and the assessment of their viability and their desirability.

The relevance of these issues to the Centre's work will now be briefly discussed.

Commodity Breakdown

Breakdown of Agricultural Commodities

It has taken several rounds of hard bargaining before the participants in the IIASA project could agree on a common commodity classification. The fact that in agriculture exports are typically more specialized than imports reflected itself in these "negotiations": each participant would like to see in the commodity list the commodities exported by his country, while at the same time a much higher level of aggregation was considered feasible and acceptable on the demand side. The final outcome is therefore a compromise and the heterogeneity of the commodities within one group, such as "vegetables", clearly poses severe problems since the model assumes full substitutability within each group.

Monetary Aspects

Money is not included in the model, although it is admittedly true that money plays a role of its own: it is treated as a unit of account and not as a store of value. For that reason the model contains the deficit on the balance of trade, which is purposely *not* labelled the national deficit. Only goods and services are considered, disregarding all monetary "commodities". In principle it would be possible to treat money as a good also, for which demand and supply functions are specified and to which particular government objectives and instruments apply. The attempts to model food and agriculture meet with considerable problems already, of which the absence of money does not appear to be the most serious one. The inclusion of money would not only be quite difficult by itself, adding to the already large problems to be faced, but would also open up a number of theoretical controversies.

The Non-Agricultural Sector

The residual non-agricultural sector produces one commodity only, which is variously used for consumption, investment, exports, processing of agricultural goods and inputs into agriculture. Non-agriculture is described by a simple macro-econometric model. The same applies here as in the case of money: one would rather prefer a more detailed treatment, but the focus of the effort on food and agriculture necessitates skimping on detail elsewhere in the model.

Data Collection and Processing

The qualification of models following an equilibrium approach puts the analyst before the task of collecting and putting together a systematic and consistent set of data by commodities, regions and income groups, describing production, income formation and distribution, trade, transfers and expenditures. These data must not only be consistent in value terms but also be brought into harmony with underlying quantity and price data. The international linkage also requires that all national models use a consistent set of net import data by commodities for past years; for that purpose strict adherence to the FAO trade data from the Supply Utilization Accounts is required. These data are used also to establish historical series for world market prices and net import quantities. In the case of Thailand the consistency of the various data has been reached by constructing a suitably formulated Social Accounting Matrix (SAM) for one selected year and by calibrating time series information on the (generally adjusted) data included in the SAM. The most difficult task has been the adjustment of production and income data to the expenditures registered by income groups in budget and household expenditure surveys. The latter also had to be adjusted to national account aggregates to the extent possible; in all cases care must be taken to preserve consistency in terms of both values and quantities (and therefore unit values).

Computation

The requirement that the national and the international model should be solvable at reasonable cost is crucial and non-trivial, because the computation of equilibria involves the solution of systems of simultaneous and nonlinear equations. For the solution of the national exchange module a special algorithm was designed. The international model is solved by implementing an existing algorithm of non-smooth optimization. These algorithms have been embedded into a simulation programme, which is currently being used by all groups participating in the IIASA project.

We now turn to issues which are more specifically related to model components.

Supply

As far as the international model is concerned, the supply module only serves as a device to generate commodity supplies at varying domestic prices and resource levels such as land, labour, machinery, herd size, etc. The decision to produce is seen as a rational process. At given resource availabilities and prices the producer determines which combination of production activities would yield the highest benefit (e.g. net revenue). The producer thus selects among the alternatives which are technically feasible to him. It is the task of the agronomists in the Centre to formulate quantitatively these alternatives. As a first approach a linear framework was selected to describe these alternatives, so that the production decision can be taken within a linear programming framework (i.e. optimization with linear objective and linear constraints).

Agronomic/Economic Interface

In order to avoid a curse of dimensionality it is necessary to design a systematic approach, for the description of the available production alternatives. As is shown in some more detail in Section III, the approach is to group the various factors affecting crop growth according to hierarchical levels, to be dealt with in sequence. The structure of the interface follows the same hierarchy. It uses the information stepwise through three computer programmes which dovetail to the linear programming module describing the production decisions. The technical information at the three levels is stored in three computer files and a fourth file is added which describes the available resources.

The size of the data files is considerable. In the case of Thailand, the first file (crop potentials) contains 5 climate regions, 3 reclamation levels, 10 different crops with, on average, 2 varieties, generating 1,500 feasible crop alternatives. The second data file contains in its simplest form a 3 x 4 matrix (four yield levels associated with zero-to-maximum applications of three material inputs) which must be applied to all of the 1,500 feasible crop alternatives. Fieldwork is described in the data file in terms of activities in successive monthly periods with their effects accumulating over time. Less than optimal fieldwork decreases net yields below crop expectations derived at the previous step. Dating of activities is of considerable importance.

Land Inventory

The agronomist does not only generate technical coefficients by synthetically building up from agronomic experience, but also uses soil maps to determine the availability of land of different categories. Both types of quantitative information thus supplement the statistical information available to the economist.

Supply Behaviour

The behavioural coefficients of an economic actor can however not all be determined on a purely technical basis.

mization upon technically feasible alternatives, does not necessarily yield realistic supply behaviour. Here two ways are open:

(a) *Synthetic Approach.* It is possible to gradually introduce more *a priori* information on producers' behaviour into the supply module. The influence of *trade margins* on subsistence behaviour has been introduced in this way in the Thailand model. There also exist practical devices to introduce *risk aversion* into optimization models. The main modelling problem in this field is related to the *intertemporal* nature of production decisions. Maximization of current net revenue does not take into account the farmer's concern for his future. This concern is thought to involve decisions on the optimal structure of assets and liabilities. Although such a description of the decision process cannot be found in the present version of the Thailand model, an application of this concept to this and following models is envisaged.

(b) *Econometric Approach.* The gradual introduction of more behavioural considerations into the linear programme improves the understanding of the system. It is, however, not necessarily an efficient approach to obtain realistic behavioural parameters and a realistic supply response. To reach this latter goal, one would like to estimate some of the model parameters in such a way that a model simulation run would best fit available time series data. Although the linear programming model is very well suited as a framework for strong technical information, it hardly lends itself to parameter estimation. A non-linear programming approach allows one to use less parameters and is better suited for parameter estimation procedures. This approach has allowed a quick parameter estimation in IIASA's simplified model and has been used in a more elaborate way for the E.C. model. Further work along these lines is needed within the Centre in order to reconcile it with the synthetic approach.

Demand

Demand Systems

The demand functions express consumer demand as function of prices and income. They describe the allocation of the consumer's budget over commodities and together form a demand system. In most countries the demand functions (including the savings function) can only be estimated by combining national time-series obtained from national accounts with household data for one point in time provided through budget and expenditure surveys. Matching of information from these two sources was one of the problems to be tackled. Several problems still remain, however. Which price should be assigned to home-grown food? How to keep a reasonable nutritional balance at increasing income? Both questions will be studied further in the context of a constrained utility maximization problem and

again the development of parameter estimation routines for non-linear optimization problems seems relevant here.

Nutritional Situation

Differentiation of regions and of income groups within regions is particularly important for the assessment of the nutritional status of population groups and the changes occurring over time. The commodity classification used as a standard in all national models provides the minimum detail necessary to obtain an insight into food intake in terms of main components – calories, protein – by income groups. The farm income groups, which can be distinguished according to land ownership classes with their own features in the production module, are central to this analysis.

An area in which further analysis is required concerns the links between nutritional status on the one hand, and indicators of health and of demographic characteristics on the other. Their significance for the assessment of labour supplies and for future demographic trends can hardly be doubted.

National Government Policies

The open exchange model provides a framework for describing agricultural policy. In the open exchange model, the national government is given the role of formulating a target price of each commodity in terms of international prices. On the other hand it can set bounds to international trade (quotas). When such a bound becomes effective, the actual price will tend to deviate from the target level: otherwise the target can be reached through imposition of an appropriate tariff/levy on international trade. Government can prevent price deviation from the target level by adjusting the level of buffer stocks. These policies involve budgetary costs/revenues, which are covered either by adjusting taxes or by adjusting government expenditures on goods and services (which include investment in agriculture). The trade deficit (value of goods and services imported by the nation) is given to each nation and no feedback relation is built in at the moment from domestic policies to the trade deficit.

It was found that this policy framework is general enough to depict the main features of government policies in countries with very different political regimes. The specific features of a nation can be brought in through the specification of the adjustment of policy targets and bounds to changing national and international circumstances. Thus, fully isolated national economies, open, liberalized economies and large oligopolistic economies can be represented within this framework.

International Government Policies

The model is designed for the analysis of international agreements. Two types of analyses can be distinguished, both testing the model of the agreement: tests can be performed on the logical consistency of the agreement as well as on the explicit-

ness of the agreement. Tests of the first type can evaluate the internal consistency of targets and constraints; for example, participants should be willing to assume the financial consequences of the agreements, and targets should not be conflicting. Tests of this type also may demonstrate that an agreement which is internally consistent is nevertheless incompatible with a given model of the real world. Obviously, that model of the real world may be inadequate but if that is not thought to be the case, then the test points at a theoretical weakness of the agreement itself.

Tests for explicitness permit the modeller to clarify the consequences of an agreement which are not expressed in an internally consistent agreement. As before, if the agreement specifies price targets and buffer stock limits but not the financial consequences for the participants, then the agreement is not adequately specified. If the agreement is even less specific – e.g. does not prescribe buffer stock behaviour at given surpluses in world markets – then the model can explain the degrees of freedom still open to participants. Finally, international agreements have indirect consequences for which theoretical insights exist but the outcomes depend strongly on the numerical values and functional specifications used. To overcome the limited insights obtained from theoretical models, one needs to solve these numerically.

Two types of agreements, internal and external ones, need to be distinguished. In external agreements, a group of countries decides to influence the state of the rest of the world, for example through cartels and producers' associations. The rest of the world is *directly and explicitly* affected by external agreements. Internal agreements like, for example, customs unions or the EEC's common agricultural (price) policy do not affect other countries directly, although there may be even substantial indirect impact. Internal agreements can be modelled without changing the basic structure of the competitive model. Participating countries can be seen as a group which operates as a unit in the world market, facing world market prices and balance-of-trade restrictions just as a country does. Trade agreements and schemes of compensatory finance are examples of such agreements.

In external agreements the countries making the agreement explicitly set out to influence the parameters they face from outside, i.e. world market prices.

It should be noted that in the system the national models can be formulated, estimated and calibrated independently for given time series of international prices and deficits on the balance of trade. Once the national models are fully specified, the exogenous prices become endogenous through the international market. The competitive model does not permit any calibration merely because it consists of imposing an international commodity balance upon the national model and does not contain any unknown coefficients.

III. THE MODEL OF AGRICULTURAL PRODUCTION POTENTIALS AND CONSTRAINTS

The economic model approach described in the preceding pages is linked to a model of agricultural production potentialities and constraints. This part of the Centre's activity is focused on the physical and agronomic factors which determine crop output in technical terms. In the preceding section a brief description was provided concerning the linkage of this technical model to the economic model. In the following paragraphs a more detailed overview is given of the technical model.

The basic assumption here is that the factors which determine crop yields can be ordered into hierarchical groupings. Also within these groups, hierarchies are established and at each level submodels are developed which are sequentially linked. At the highest hierarchical level, where the analysis starts, only one factor is variable and it is assumed that other factors, at lower levels, are not limiting. Subsequently, when the analysis moves to the next lower level, only the next lower factor is variable, whereas the lower ones remain not-constraining and the higher ones are fixed.

For example, the first-level analysis concerns solar energy and provides for a specific area the calculated gross CO_2 assimilation of a standard crop, assuming that other factors like available water, nutrients, diseases or available labour are not limiting. At the next level, the analysis turns to the soil-water regime and assesses the extent to which the gross CO_2 assimilation is converted into dry-matter production under constraining water availability. At this second level, the other (lower level) factors like nutrients, diseases and available labour remain, by assumption, not constraining.

Short Model Description

The hierarchical sequence consists of the following main components: solar energy, temperature, available water and available plant nutrients. These factors change in the course of the growing season. Therefore the simulation model of crop production employs time intervals. These intervals need to be as short as possible, because during each time interval a steady-state situation is assumed. Periods of ten days are considered reasonable for simulating crop growth.

The first factors considered are *solar energy* and *temperature*. At each site and for each time interval solar energy and temperature can be measured. They determine photosynthesis and respiration and thus the dry-matter production of a crop. A distinction is made between C_3 and C_4 crops as those differ significantly in their photosynthesis pathway. The examples of wheat and rice used below relate to relatively less efficient C_3 crops. The gross CO_2 assimilation of the standard C_3 crop is calculated for all time intervals in the growing season of the crop. Addition of these partial production figures yields the gross CO_2 assimilation of the crop.

The second factor considered is the *amount of water* in the soil that is available for the growth of the crop during each time interval. Shortage of water during some parts of the growing season is common to most crop systems and consequently the factor "available water" for crop production is introduced at the second hierarchical level. For this the physiology of the crop during its various stages of development must be known. The calculation of available water for each time interval is rather complicated because it depends on crop, land and soil characteristics, precipitation and evapotranspiration, i.e. evaporation of water at the soil surface and transpiration of water by the crop, and on interference by man (irrigation). In order to know the amount of available water at the time when seeds germinate, the conditions preceding the time of sowing have to be taken into account as well. The whole procedure is described by a water balance for which a special submodel has been developed. For this model as well as for other submodels, ample use was made of models that were developed in recent years by others. With the aid of the water balance the already calculated dry-matter production of a standard crop is converted into the potential dry-matter production of the crop at hand (wheat or rice) at a particular site and under a defined water regime. Crop studies allow us to estimate the portion of the dry matter distributed over seed and rest, consisting of straw plus roots and stubble at each time interval, giving at harvest the maximum seed production at the chosen site under the prevailing conditions of available water and under the assumption that all other production factors are not limiting. The potential yield can be increased by measures of land amelioration that increase the amount of available water or by breeding new crop varieties that make more efficient use of the available water, or both. The application of these submodels results in an estimate for each crop or crop variety of the area specific feasible yield.

The next production factor considered is the availability of material inputs, particularly *plant nutrients* and *crop protection chemicals*. So far, all factors influencing the growth of a crop besides solar energy, temperature and available water were assumed non-limiting. But commonly there is a shortage of plant nutrients, particularly of nitrogen. A host of experiments on natural soil fertility, on the application of manure and compost and on the application of artificial fertilizers have been published. Studies of the uptake of NPK by crops and of the efficiency of certain fertilizers are also available. The submodel on plant nutrients indicates implicitly the level of technology. No fertilizers are applied at a low level of technology and crop yields then depend on natural soil fertility. At higher levels of technology application of fertilizers is part of the farm management system. If the nutrient status of the soil is known, the calculated potential yield can be transformed in the yield at a specific nutrient level.

Similarly the application of herbicides, fungicides and pesticides can be included as an element of technology. Some problems can arise in this case as their application has a stepwise character, with cumulative effects. The third level in the

hierarchy concerns *fieldwork*, consisting of the preparation of the land, protection of the crop during its growth (notably weed control) and harvesting. These are time-sequential farm activities performed with substitutable means of manual, animal or mechanical power. The model prescribes a particular sequence of work which must be performed; shortage of labour, resulting in less than optimal field work, has a negative effect on net yields. Knowledge of the various loss factors involved is not very detailed (except for weed control) and it is therefore only in few instances possible to estimate the relationship between intensity of field work and the effects on yield.

In addition to these factors, several other production factors are successively introduced in the model. Submodels for these factors deal with the possible reductions of expected yield and determine in the end the real yield.

This short outline of the simulation model for crop production explains the hierarchical approach and shows that the model is open-ended because more factors can be introduced, should the need arise.

In addition to an estimate of production, it must also be known how much labour and capital are needed to obtain the calculated production. Therefore the model is extended to assess these needs. The model also allows calculation of the use of *fossil energy* needed for the production, maintenance and utilization of machinery and for the means to increase and to protect crops.

The structure of the model as outlined above is not very complicated. It is made for one crop, growing at one particular site, at a time. In a farming system more crops are grown in rotation. These crops are grown at a great many sites with varying climate and soil conditions under four possible levels of land reclamation and/or amelioration. Furthermore five levels of technology have been distinguished. This adds up to a very large number of possible combinations that could be worked out. In actual practice this is not done. An intelligent choice has to be made to narrow down the theoretical possibilities to a limited number of farming systems that are considered relevant for the purpose of the study.

Crops are given at a great many sites. Each site has its specific characteristics (soil conditions, topography, hydrology, climate, level of reclamation etc.). Data are available from soil and topographical maps, from weather stations, etc. Special methods have been developed to determine the specific site characteristics for hundreds of units of a grid system that covers a country. Each grid unit is characterized by map coordinates. All information is stored in the computer for each grid unit, and consequently all calculations as discussed before can be made for each site. The results can be shown on cartograms that are printed by the computer.

As a matter of fact, the whole exercise can only be made if data of the various factors to be taken into account are available, or if reliable estimates can be made. Knowledge of some factors is still incomplete. A major advantage of the hierarchical approach to the problem of crop production is that available partial knowledge is used to the maximum.

The research work presented here never has been done before. Some submodels or similar submodels have been developed for specific research purposes. The approach, as developed here, to compute a quantitative crop production and to analyse alternative systems of farming is new. The combination of research on crop production in various farming systems under defined environmental and socio-economic conditions provides a quantitative basis for land evaluation, a subject that attracts much attention at the present time.

IV THE THAILAND MODEL: AN APPLICATION

A model for Thailand constitutes the first attempt to apply the methods described above in the agronomic and economic fields to a specific country. Thailand was chosen as it has, amongst developing countries included in the list of countries selected for the international model, a relatively good data base. Modelling is also made easier by the fact that the country has a good record of stable economic growth and has not experienced major changes in policy objectives.

The economic policies of Thailand have been characterized by reliance on private economic activity and limited government intervention. Although successive Plans emphasized the importance of promoting economic growth, this did neither translate itself in a particular sectoral emphasis, nor in significant public sector investments except in infrastructure and support facilities. The main concern of the government has been with the stability of domestic prices, which was translated in terms of a fairly liberal external trade regime and conservative fiscal and monetary policies. External influences on the Thai economy were mitigated by a variable levy on exported rice — for many years the leading export item —, flexible credit policies for the financing of foreign trade and the cushioning of the balance of payments with sizeable foreign exchange reserves.

Changes in the structure of the economy have been slow, as growth took not only place in the modern sectors but also in agriculture. The diversification of agricultural production over the years is noteworthy, particularly because it reflects to a large extent new opportunities in international trade. This balanced growth has kept migration to the cities within reasonable bounds.

Still, regional and intersectoral income disparities are quite substantial; the distribution of income, both between regions and within agriculture, has not changed much notwithstanding overall economic progress. The oil price increases since 1973 have affected domestic prices and also the balance of payments which has shown sizeable inflows of external capital in the last 6 years; the debt situation remains favourable. The inflow of capital serves largely to cover sizeable deficits in government budgets which partly arise as a consequence of rising public investment and for another part from sluggish tax receipts which have fallen behind current expenditures

in years of faster-than-usual domestic inflation. The agricultural sector is diverse, both in terms of the natural conditions and in terms of the pattern of output. Its growth has benefited from reasonably good price policies, the availability of land which could be brought under crops and the promotion of irrigation and (more recently) the use of fertilizers and increased crop protection. Trends in population, land ownership and agricultural production have raised rural incomes significantly and the impression exists that rural poverty has been considerably reduced over the past 20 years. As particularly the possibilities for opening up new land are now becoming smaller, it will be interesting to see under which policies these favourable developments can be expected to continue.

The model distinguishes five regions: Northeast, North, Centre, South and Bangkok. For two of these regions, a further subdivision was deemed necessary in order to get homogeneous agricultural production zones (cf. *infra*). In each region there are four groups of producers: small, medium and large farmers and non-farmers. To each farm group there corresponds one income class. The functional distribution of income or, in other words, the distribution that is linked to asset ownership is fully endogenous for the agricultural sector. Non-farm income in each region is distributed between three income classes. The share of these non-farm income groups in the value of non-agricultural production is determined *a priori* on the basis of the 1976 budget survey. This does not exclude the possibility of examining the effects of a change in non-farm income distribution on the economy. By convention, farmers produce the 18 agricultural commodities of the IIASA classification and non-farmers produce the one non-agricultural commodity. In order to be realistic, some exceptions were allowed on this rule (e.g. marine fisheries is done by non-farmers).

It will be immediately obvious that the detailed commodity-region and income group breakdown leads to considerable data requirements. A lot of manipulations were necessary to convert available published and unpublished material into the required classification format. In order to facilitate these manipulations, a social accounting matrix (SAM) was developed for the base year 1973. The SAM is a statistical representation of all the current transactions of the economic agents. The SAM also served two other purposes, namely:

- (i) To achieve consistency between the detailed agricultural production data, and the detailed expenditures, savings and tax data from the household budget survey as well as the national and regional accounts; and
- (ii) To facilitate the determination of several model coefficients (e.g. the processing requirements that are necessary to convert raw farm produce to final demand categories).

For each economic agent the SAM records all expenditures and receipts. For example, for farmers receipts can be

- (i) Revenue from the net production of agricultural commodities;
- (ii) Revenue from working on other farms;
- (iii) Revenue from working for the non-farm sector inside the region, or in another region; and
- (iv) Revenue from transfers (government or international).

Payments for farmers include

- (i) Consumption of commodities,
- (ii) Savings, and
- (iii) Direct taxes.

The SAM is presented in value terms; in order to derive a consistent set of prices, it has to be complemented with a set of quantity balances for the commodities.

The Thailand model can roughly be divided into two main components: the exchange component and the supply component, which will be described below and in that order.

The Exchange Component

This part of the model consists essentially of a system of simultaneous equations which is solved to derive the equilibrium price for the 19 commodities. The equilibrium price is the price that clears all commodity markets after allowing for international trade, and taking fully into account the restrictions imposed by government policies. In equilibrium, each economic agent satisfies his budget constraint.

Demand behaviour for food is represented by a set of demand functions specifying relations to income and prices. Demand functions for each income group were estimated combining cross-section information of the 1976 budget survey with the time series expenditure data of the national accounts (1960–76). For each income group a savings function is also included. Available savings determine investment. A share equation allocates available investment funds between the public and private sectors and between agriculture and non-agriculture. The data basis used to estimate these share functions is scanty and it will require extensive use of sensitivity analysis to validate these functions. Further equations are necessary to explain government demand (both investment and consumption).

Government policies are represented through tax rates (excises, income taxes and tariffs). These tax rates are derived from the SAM. For some commodities (e.g. bovine meat and pork) quotas on international trade are imposed. These quotas reflect the inflexibility of the transport and processing infrastructure. For important commodities, such as rice, a price target function of the government is included.

The exchange component takes supply of agricultural and non-agricultural commodities as given. This is reflected in a fixed endowment for each

income group. Agricultural supply is determined in a detailed linear programming model (cf. *infra*). Non-agricultural production is determined by labour and capital using a production function with a constant elasticity of substitution. Labour supply is determined by an employment function. Capital supply depends on past investment and an exogenous depreciation rate. Full utilization of production capacity is assumed. When the equilibrium price is determined, the agents can carry out their expenditure plans and another round of supply and exchange can start. One cannot know who is selling rice to whom; only the final result is recorded.

As a first approximation for Thailand it is assumed that all producers face the same price and all consumers face the same price. Available statistical evidence shows that regional price disparities are fairly small in Thailand. For the time being, the same processing level will be assumed for all income groups. This assumption is not realistic and will have to be modified in due course.

From one period to the next, several adjustments take place:

- (a) Population growth takes place at an exogenously specified rate (the slight decline in fertility observed from 1970 to 1976 will be extrapolated; also observed participation trends will be used).
- (b) Migration decisions are carried out; permanent migration depends on the income differential between the rural area and Bangkok. Migration trends have not been dramatic in Thailand for the past 10 years in contrast to other developing countries.
- (c) Investment is added to the capital stock (other resource adjustments take place in the agricultural section; cf. *infra*).
- (d) Several coefficients are adjusted (e.g. demand function parameters are changed so as to let demand for food satisfy nutritional restrictions).

These adjustments can be made to reflect particular government policies and can thus be used to trace the consequences of alternative development policies.

The Agricultural Production Module

The farm sector in Thailand is a very decentralized decision-making system made up of about 3.5 million fairly independent farmers. Given the nature of his environment, which consists of all other farms, the markets for inputs and outputs, physical conditions, infrastructure, government policies, all kind of institutions, etc., the individual farmer tries, on the basis of limited information, to reach his goals. This basic characteristic of the Thai agricultural sector is the starting point for the formulation of the supply module. For the individual farm the possible (inter) actions and the environmental constraints have been described. Obviously, it is impossible in quantitative work to describe "the state of affairs" for all farms. Therefore the behaviour of representative farms has been modelled. These models have

been used as the basis for describing the behaviour of the sector as a whole. Similarities in farming structure, i.e. in farm size, topography, climate, etc., were the selection criteria in determining the representative farms.

In Thailand we can distinguish six more or less homogeneous agricultural regions:

- (1) Northeast,
- (2) Upper north,
- (3) Lower north,
- (4) Central plain,
- (5) Eastern/western parts of the Central region, and
- (6) South.

Within each region three farm sizes were distinguished:

- small farms (0 – 10 rai),
- medium farms (10 – 30 rai), and
- large farms (> 30 rai).

In this fashion 18 representative farms (6 regions x 3 farm sizes) were modelled. In modelling a representative farm, emphasis has been given to the main factors only, which influence the decisions regarding the farm and non-farm production processes. For the average Thai farmer these main factors are

- (1) The competition among different outputs for the same inputs (cf. land, labour, etc.);
- (2) The integration of animal and crop production;
- (3) The possibility of performing production activities with different input combinations (technologies);
- (4) The integration of the household and the farm;
- (5) The possibilities of earning an income outside agriculture;
- (6) The attitude towards risk and uncertainty;
- (7) The influence of the government;
- (8) The interactions with the physical environment; and
- (9) The interactions with other farms.

One way to formulate the problem in a manner which makes these factors explicit is in the format of activity analysis, and the methodology best suited for this purpose is that of *recursive linear programming*. A recursive linear programming model consists of four elements: the activity set, the constraint structure, the objective function and the dynamics of the resources. We will briefly discuss these elements.

(A) The Activity Set

We can divide the activities into six types.

(1) *Production Activities*. This group is by far the largest. A production activity consists of several tasks. For instance, for growing paddy the following tasks have to be carried out: land cultivation, sowing, transplanting, weed-

ing, fertilizing, crop protection, harvesting and threshing. If these tasks can be performed in more than one way, then each alternative is brought into the model as a distinct activity. For each region/farm size, three kinds of production activities are distinguished:

- (i) Crop activities (8–12 in number); (ii) livestock activities (5) including inland fisheries; and (iii) non-agricultural production activity(1).
- (2) *Sales and Purchasing Activities*. These activities are related to the sales and purchasing of outputs (paddy, cassava, eggs, etc.) and inputs (fertilizer, feed, biocides, etc.) respectively.
- (3) *Hiring and Renting Activities*. This group includes the renting and hiring of labour and tractor power and also the borrowing of money.
- (4) *Subsistence Activities*. The traditional Thai farm is a subsistence farm. Although increasing quantities have been produced for the market in the course of the past decade or so, the proportion of production for own consumption is still considerable. This subsistence production is not only the consequence of the attitude of the Thai farmer towards risk, but also of the fact that by producing for own consumption the trade margin is earned. In the model the possibilities are open for the farmer to produce for own consumption, up to an upper limit of each crop (e.g. vegetables, fruit, eggs, poultry meat or pork).
- (5) *Migration Activities*. Two kinds of migration activities are distinguished: permanent migration and seasonal migration. Both activities refer to migration within the region. Migration to Bangkok is treated in the migration module outside the L. P. Model.
- (6) *Investment Activities*. A distinction is made between public and private investment. In the first version of the model both investment types take place in the investment module. Ultimately, however, private investment (in tractors, reclamation, etc.) will be included explicitly in the recursive linear programming model.

(B) The Constraint Structure

We can divide the constraints into two types.

- (1) *Resource Constraints*. The main resources are land, labour, fertilizer, animals, tractors and cash.
 - (a) In the model six land classes are distinguished: (i) flooded lowland; (ii) rainfed lowland; (iii) wet season irrigated land; (iv) dry season irrigated land; (v) upland; and (vi) permanent fallow + pasture.
 - (b) Labour is expressed in available hours per month. During the planting and the harvesting seasons there is a possibility for making overtime. Labour of children can only be used for cattle and buffalo herding.

- (c) Six types of livestock are distinguished: buffaloes, cattle, pigs, poultry for meat production, poultry for egg production, and fresh-water fish.
- (d) Tractors. The number of tractors determines together with the number of buffaloes and cattle, the availability of draught power.
- (e) Fertilizer is constrained at the national level. Organic manure is expressed in fertilizer equivalents; the quantity is determined by the number of animal activities.
- (f) Cash. A certain percentage of last year's income can be used for buying non-farm inputs. The available cash can be extended by means of borrowing from banking institutions. The borrowing capacity of these institutions is regionally constrained.

(2) Behaviour Constraints

- (a) The demand for home-produced goods has an upper limit. This upper limit is adjusted from year to year according to a set of demand functions that depend on income and prices.
- (b) The flexibility constraints place both upper and lower limits on the extent to which farmers are willing to increase or reduce output of any given crop or type of livestock in response to profitability in the previous year(s). This cautious response is due to
 - (i) conservative attitude towards change; (ii) a desire for diversification; (iii) the expectation that the profitability may be short lived; and (iv) lack of infrastructure (market channels) which are not explicitly brought into the model.

(C) The Objective Function

We assume that the Thai farmer carries out the activities with the following objectives in mind: (1) meet family requirements for food; (2) maintain the production capacity of the farm at least at the same level; and (3) after these first two objectives have been met, try to maximize income. The first two objectives are translated into constraints. The third objective is brought into the objective function of the model.

(D) Dynamics of the Resource Structure

Every year the resources (as well as the price expectations) are adjusted on the basis of interactions with the other sectors of the model and the outcome of the production module in the previous production period. Partly these adjustments are exogenous, for instance the increase in irrigated land area till 1990 has been estimated in accordance with the current plans of the Thai government. The change in available labour is the result of population growth and migration. Savings by farm-size group are generated as an output of the exchange module. These savings function as a variable in the investment module, and determine the investments in new

farm equipment. In the first version, investments in cattle and buffaloes are exogenous; investments in other livestock are based on expected profitability with an exogenously estimated upper limit. The parameters of the behaviour constraints are constant during the time period of the model. They are estimated on the basis of historical behaviour.

(E) Data Base

To estimate the model a huge quantity of data is needed. The two main sources of information are:

- (1) Actual Thai and other (statistical) publications; and
- (2) Technical data generated by the Wageningen group.

V. FURTHER WORK

In the course of 1980 it is expected that nine national models (amongst those the Centre's model of Thailand, and a model for the EC) will be delivered to IIASA. The structure of the models for four others will be ready and parameter estimation well under way, whereas the country network is expected to be extended further with at least five other countries. The number of modelled countries is expected to increase further in the course of 1981.

The completion of an international model containing the desired number of around 25 fully specified national models may still be some years off; spacing the completion of national models in succession over time also creates the need for considerable staff resources to update the ones completed first. For many of the participating countries and/or institutions the core of their interest is to see their national model operate as part of the international linkage. Therefore it was considered desirable to put a special effort into a separate task of constructing highly simplified national models in a sufficient number to permit demonstration runs with the international linkage. The first demonstration of, and with, the simplified system took place in November 1979 at IIASA. It will from now on be maintained and permits the inclusion of the more detailed models into the international linkage at once, when those are completed and can substitute for the simplified versions now used. This set-up has greatly added to the attractiveness of the project for newly joining research institutions.

In the course of 1979 more defined relationships have been established between FAP and other on-going research at IIASA in the area of resources and technology. This has resulted in the formulation of a second research task (the first being the economic research effort) linked to the first. Its objectives are to study the interactions between resources, environment and agricultural technology and to develop and test models constructed for these purposes. Close links are sought for this new programme with the Centre and particularly with the agronomic group in Wageningen.

Country modelling requires considerable knowledge which usually is concentrated within the country itself. Therefore it is desirable to entrust this modelling work to institutes in the countries concerned with whatever outside support they may need. Alternatively when models are made outside the country, the least requirement should be to engage local expertise in the effort. The Centre's work on Thailand belongs to the second category, and this particular approach was taken because at the time of its inception the methodology of the work had not as yet been fully established. Particularly the feasibility of developing an interface between agronomic and economic analyses had not been demonstrated, whereas at the same time it was realized that constraints would exist on both sides, limiting the choice of methods in each area of work.

The Thailand model is therefore considered to be a pilot study for which no formal cooperative arrangements should be made with institutes or agencies in that country. Informal contacts were, however, frequent and intensive. With a number of major methodological problems now resolved, the next country modelling effort will establish first a more formal research agreement with an appropriate counterpart institution which distributes tasks and responsibilities and sets up coordinating mechanisms. An important aspect of the latter will be the search for closer ties to policy makers in agriculture in the country concerned which may lead to relevant choices between alternative policies in running the model and may also help them to better understand the implications of the policies they implement or consider.

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