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Dynamic Model of Farm Resource Allocation for Agricultural Planning in Korea--Application of Recursive Programming Within a General System's Simulation Approach

Project Working Paper 72-1
Preliminary draft without simulation results.

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1. Purpose of the Study

The following study is part of a comprehensive agricultural sector analysis for Korea under AID. It is concerned with the incorporation of a Recursive Linear Programming (RLP) Component into an existing General Systems Simulation model. A full understanding of background and economic-political framework requires therefore knowledge of the research of the Korean Agricultural Sector Study (KASS) team reported elsewhere [22]. This report is the result of a relatively short term project, mainly a 6 weeks stay in Korea by the authors. It therefore requires further revisions and does not yet contain simulation results. Its main purpose is to discuss the major scope of the model, its linkage to components of the existing General Systems Model (SIM) and the detailed structure of the RLP component.

The existing General Systems model for Korean agriculture does not contain an endogenous explanation of resource allocation and production and uses exogenous projections for each policy alternative. By incorporating the RLP component into the existing SIM model we are attempting to represent farmers' decisions with respect to land allocation, livestock production and farm mechanization endogenously in the model. The combined model makes it possible to investigate the supply response to various price and market policies, as defined in the four policy alternatives of the sector study. At the same time it views the farm sector as part of a more comprehensive system in which agriculture interacts with the rest of the Korean economy and society on various levels and in varying intensity.

Since resource allocation in time and space as well as farm mechanization and agricultural production in Korea are an integrated reflection of technical change, of major product and factor price policies, of resource development and other market conditions, it seems necessary to describe briefly the alternative policy strategies and general assumptions for which different projections until 1985 are being made. The KASS-team defined basically three policy alternatives:

I. A continuation of the agricultural and rural development strategies laid down in Korea's current Third Five-Year Plan (TFYP).

II. A modification of the TFYP along lines actually followed since the inauguration of the plan.

III. A policy strategy including greater reliance on international markets with a competitive domestic market and more emphasis on industrialization of Korea.

The major policy goals for agricultural development of alternative I are: (1) to increase agricultural production toward full self sufficiency, (2) to increase agriculture's relative share of national income and (3) to improve the "quality of rural life" in general. Alternative II retains the general policy objectives of I, but seeks increased effectiveness on all levels by changing the structure of public investment, putting more emphasis on population control and increasing expenses for extension and research. Alternative III assumes free trade policies for agricultural products and inputs and a departure from governmental price supports in domestic markets. The following figure summarizes the three policy alternatives:

Figure 1:

Summary of Policy Components of Alternatives II and III Relative to Alternative I (TFYP)

Policy Component	Emphasis or position relative to Alternative I	
	Alt. II	Alt. III
Research and Guidance Programs	More	Same
Land and Water Development	Same	Less
Labor Substitutes	As needed	As needed
Food Price	Higher	Lower
Import Policies	Same (Restricted)	Open
Infrastructure Investment	More	Less
Family Planning Program	More	More

In addition to these three alternatives, there is a fourth in which the experiences from simulation runs with alternatives I to III will be used to derive "new and more promising" strategies for agricultural development in Korea.

2. Problems Related to Resource Allocation and Mechanization in Korean Agriculture

Reallocation of resources in agriculture and particularly the mechanization of basic -- thus far relatively labor intensive -- activities in crop production appear to be necessary conditions for further economic development in Korea. While the Korean economy as a whole has been growing very rapidly during the last decade, there were considerable differences among major sectors. In the period between 1959 and 1969 the growth rate of GNP (in 1965 prices) was 8.2% for the economy, but only 4.5% for agriculture. Hence, the major contribution for economic development did obviously come from the industrial-urban complex, while factor productivity and aggregate production in the farm sector remained relatively unchanged. A continuation of this development in the next decade in connection with the actual population growth rate of about 1.8% would very likely create problems of food shortage and an unsatisfactory income distribution between agriculture and the rest of the economy. These trends would even be worse given the extensive resource transfer from agriculture to other sectors.

The magnitude of these problems will certainly depend on the effects of major factors affecting demand for agricultural products on the one side and the intensity of adjustment processes taking place in agriculture on the other side.

Demand for Agricultural Products

Major factors, among others, determining the domestic demand for agricultural products in the long run, are the size of the population and the level of per capita incomes. Despite the fact that the population growth rate has been decreased from 2.8 to 1.8 percent between 1960 and 1970 due to successes in family planning, the KASS projections do still project a total increase in population between 24.6 and 27.1 percent from 1970 to 1985, depending on the intensity in family planning [22]. In addition to that, projections indicate a 7% growth rate of per capita GNP during the period of the Third Five Year Plan (1972-1976) [21] and a continuation of similar magnitudes in economic growth until 1985. Although estimates of income elasticities vary with data sources and mathematical models, it seems safe to assume that livestock products, fruit and some vegetables will have positive elasticities > 1, whereas food grains will have positive elasticities < 1, some even negative. [11]. What this indicates is that not only will the aggregate demand be considerably increased, but differential growth rates of various commodity groups will also lead to changes in the composition of demand and thus change the equilibrium of factor earnings among enterprises in agricultural production.

Resource Transfers

Another area where compensating adjustment processes in the farm sector will be necessary, is the resource transfer out of agriculture, often considered as one of agriculture's major contributions to economic development of a country [10]. In the case of Korea this refers mainly to land and labor. According to KASS' informal projections, around 200,000 hectares of agricultural land, which is approximately one tenth of the farm land in 1970, will pass from farm to non-farm use until 1985. This will not be compensated by the amount of land reclamation which will add some marginal areas to the existing agricultural land [14]. A more critical issue is the continuous withdrawal of people from the agricultural labor force. Projections indicate that the relative share of agriculture will drop from the current 50% to 22% in 1985, which would be a decline in the absolute size of the rural population by approximately 55% between 1970 and 1985. Theoretically one might expect that labor productivity and per capita income in agriculture would rise due to a reduction of the labor force, but given the technology of Korean agriculture this would probably not be true unless new technologies are introduced and the functioning of the machinery and land markets is improved. The absence of those dynamic forces would very likely lead to a considerable decline in agricultural production in the process of labor withdrawal.

In short, the discussion so far is equivalent to saying that the Korean agriculture faces the problem of feeding more people with food of better quality and changing composition while using less land and less labor than now. The question to be analyzed in this study is how the farm sector will adjust resource allocation and introduce less labor intensive technology under various policy strategies, i.e., how agriculture can be influenced to make a sound contribution to overall economic development.

Technological Change and Farm Mechanization

The type of technologies suitable for a specific nation depends on the stage of economic development and on the character and composition of the available resources. Historically, Korean agriculture has been using to a great extent "land saving" biological technology. Given the policy target of food self sufficiency on the one side and the existing potential for yield increases on the other side, biological progress will certainly have to be emphasized in the future also.

However, according to the aforementioned trends in economic development, it seems to be the right time to introduce mechanical technological change as well. The questions to be answered here are: Which types of farm work need to be mechanized? By what criteria should mechanization programs be selected? Which type of mechanization is not only physically but also economically feasible? And what will the time path of mechanization be under alternative policies? The Exotech report on farm mechanization treats these questions only partly [8].

As to the types of farm work to be mechanized, it is necessary to find labor peak seasons and to investigate mechanization during that time. For Korea this leads to the consideration of planting or transplanting and harvesting of rice and other grains as peak seasons in June and October [16]. As a general source of power for land cultivation and transportation, the introduction of power tillers to replace draught animals might probably have a considerable labor saving effect and at the same time set feed crop areas and farm capital free for livestock production for human consumption.

The actual investment to mechanize a particular group of enterprises on the farms will depend on many factors, including effects of technological change in competing enterprises on the farm, governmental price and market policies, farmers' financial positions, to mention some of the factors. All together determine farmers' decisions with respect to enterprise combination and capital accumulation. It is this interdependence of various farm activities which led us to the selection of a dynamic activity analysis approach. By investigating the physical and economic implications simultaneously, the approach is essentially different from the Exotech study, which is basically a technically oriented static analysis.

We assume that to the extent that economic development takes place, farm production will be more and more commercialized leading to more specialization depending on differences in resource mix, natural and economic conditions between farms. The study is therefore based on a regional disaggregation of Korea, assuming that each of the three regions, defined by the KASS team, has comparative advantages for some specific products. Moreover, since the total level of production of certain products (tobacco, raw silk) is regulated by the government, the different locations compete for high shares of those quotas. In other cases (like vegetables) the absence of any public price stabilization may also lead to a relatively strong influence of location factors and hence regional specialization.

The study tries to incorporate these spatial dimensions of agricultural production by projecting allocation and production response for each of the regions and at the same time taking into account the interactions among those regions.

3. Methodology

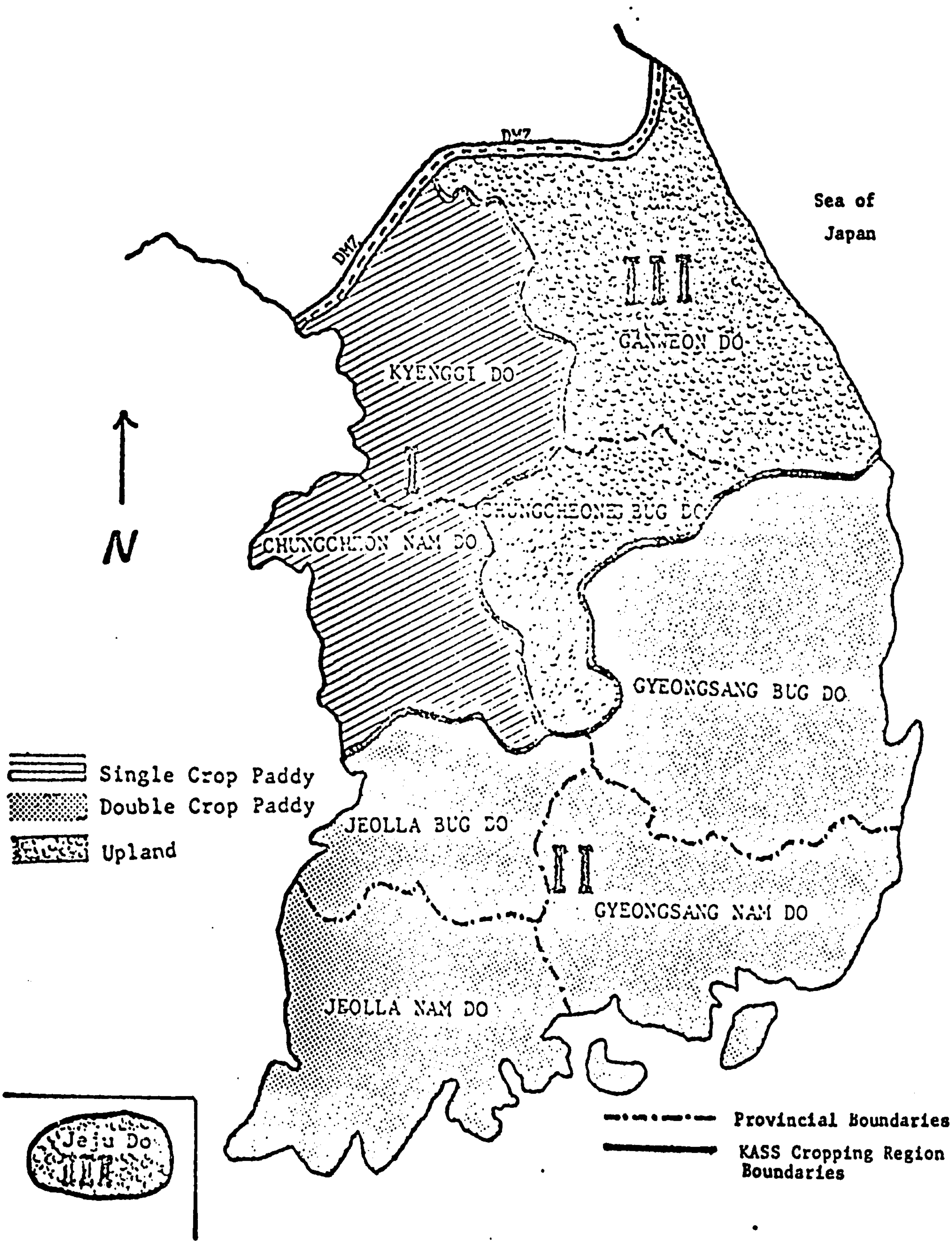
3.1 The General Scope of the Approach

As it was indicated in the introduction, the project is not independent in itself, but is part of a broader and more comprehensive agricultural sector analysis including the development of a General System's Simulation model for Korean agriculture.

Due to spatial differences in climate, topology and soil fertility three production regions are distinguished. For each of them regional production functions are defined. Likewise prices for inputs and products are determined at the regional level. The delination of the regions can be studied from the following map. Region 1, the "single cropping paddy region" is located in the northwest around Seoul and can be characterized by rice production without a following winter crop in most cases. Region 2, the "double cropping region" in the south is characterized by a sequence of summer crops (mostly rice) and winter crops. Region 3, the "mountain region" in the east is not suitable for paddy rice production in most areas. Upland cropping is the major pattern in this region.

The model distinguishes among the following 19 commodities or commodity groups:

1. Rice
2. Barley
3. Wheat
4. Other Grains
5. Fruit
6. Pulses
7. Vegetables
8. Potatoes
9. Tobacco
10. Forage Crops
11. Mulberries
12. Industrial Crops
13. Beef
14. Milk
15. Pork
16. Chicken
17. Eggs
18. Fish
19. Agricultural Residual



Provincial and Cropping Region Boundaries of Korea

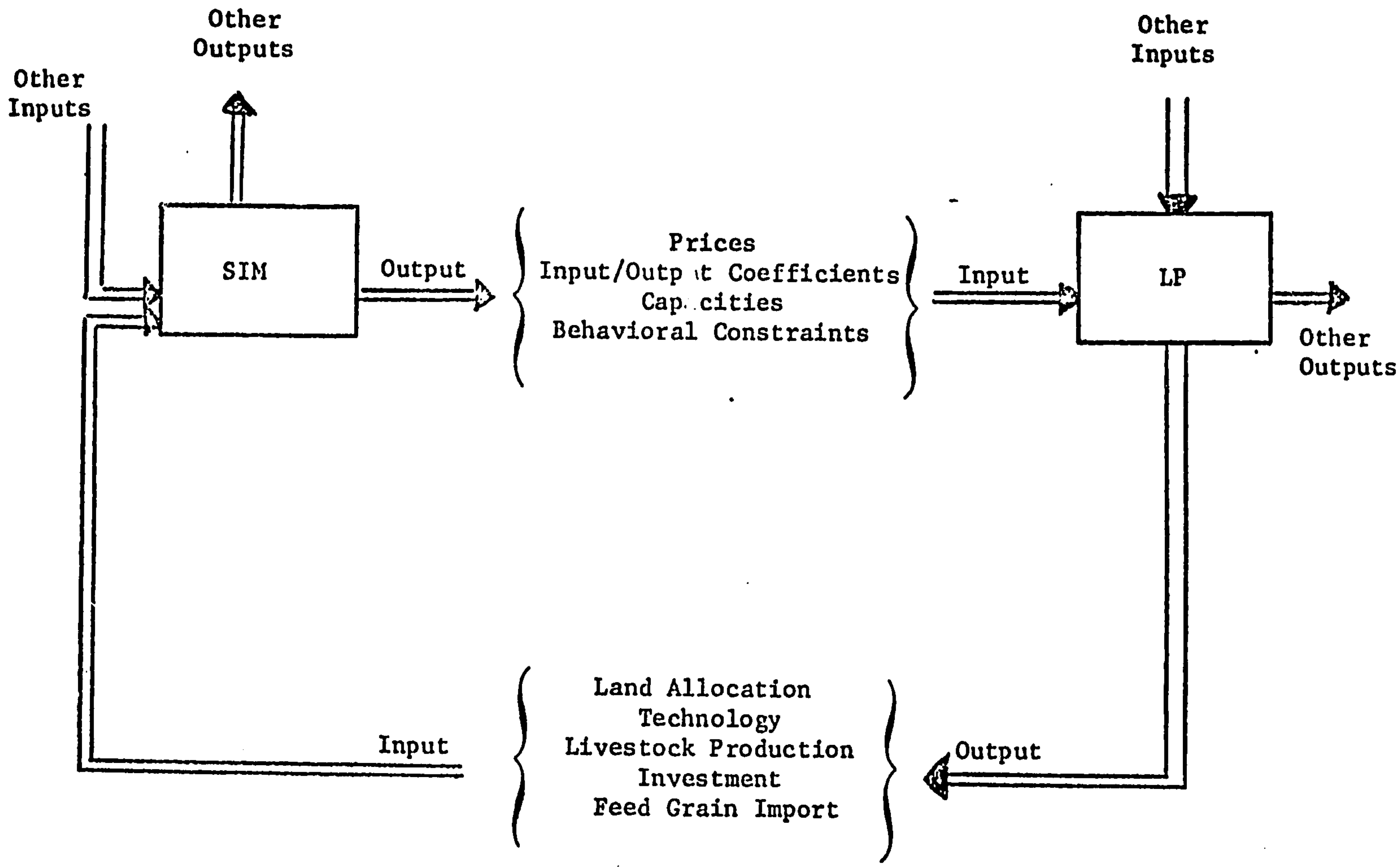
Based on a building-block-approach, the existing General System's Model consists of various interacting components, representing major parts of the agricultural sector and the non-agricultural economy as well. The Recursive Programming Model supplements the existing model with a production and supply response component. It consists of a sequence of recursively linked Linear Programming components. The following diagram gives a general idea of the linkage between the linear programming component and the other components of the system's model (Figure 3.1).

The following chapter contains a description of the 1) main components of the existing General System's Model and 2) of the Recursive Decision System. The last part of the chapter will summarize the major features of the dynamic linkage between both systems.

3.2 The General System's Model and Main Components of the Current Version

The current version of the system's model of Korea's agriculture may be characterized as a set of model components representing different sub-sectors and institutions of the sector or other systems affecting the performance of the agricultural sector. The components are either interacting recursively as the behavior of the system is simulated through time or they are independent (like the national input-output model and the demographic model) and used for exogenous projections for inputs of other components. The structure of the components themselves is mostly completely recursive, i.e., they consist of recursively linked single equations. Some of them, like the urban demand and the national two sector model (and in the new version: the yearly LP model), contain also systems of simultaneous equations.

Figure 3.1: Dynamic Linkage Between Components of the General System's Model (SIM) and a Linear Programming Component (LP) within the Recursive Decision System



Main Components

Since the model is described by its authors elsewhere [22], it is enough just to summarize it here. The structure is schematically shown in Figure 3.2, which is taken from the aforementioned publication [22 , p. A3].

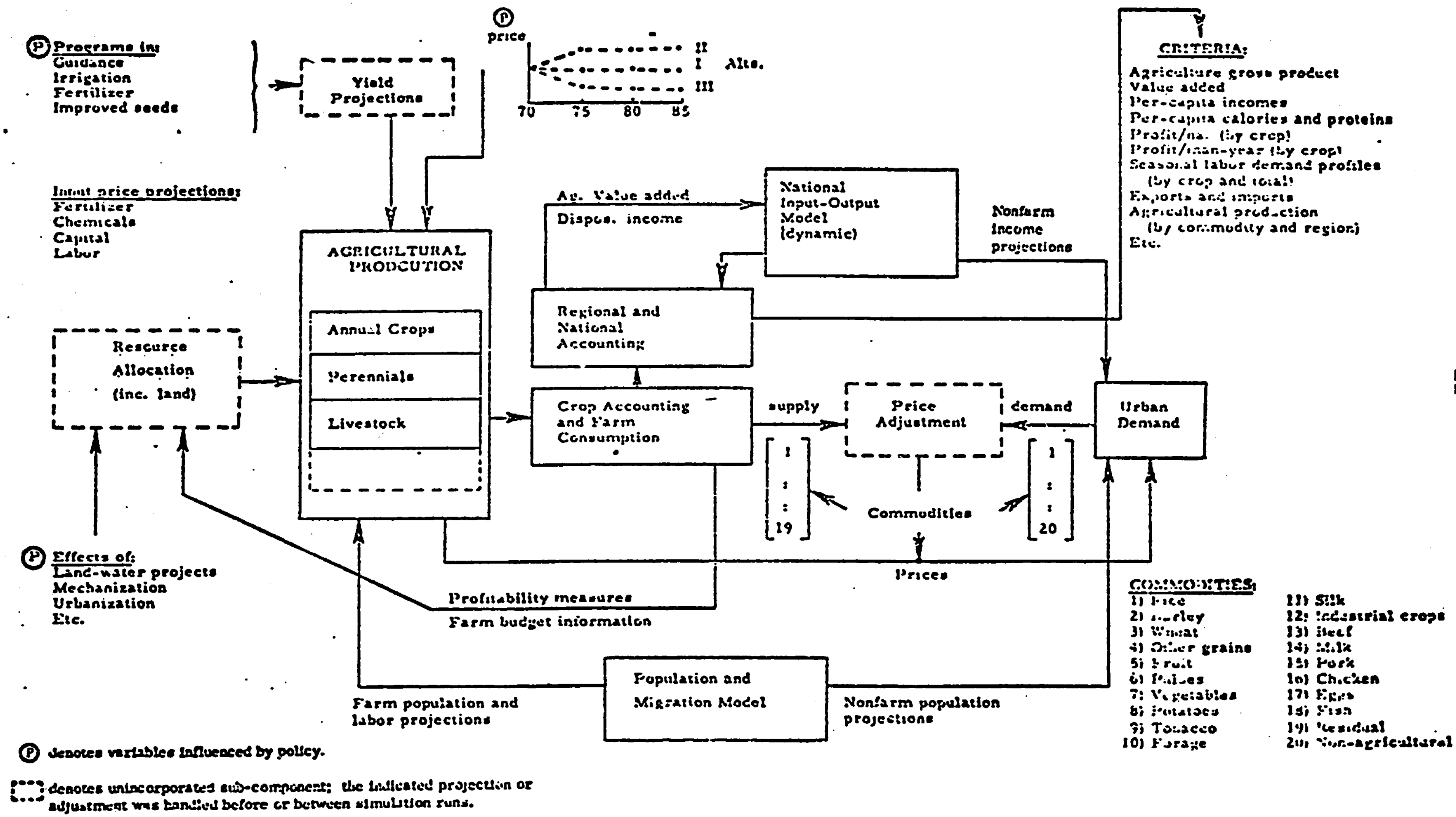


Figure 3.2. Diagram of Iterative Operational Model of Korean Agricultural Sector Actually Used to Project Consequences of Alternative Policy Strategies

Source: [22]

The major components which represent the economic operation of the agricultural sector are

1. Production and Market Supply
2. Urban Demand
3. Grain Management
4. Population
5. National Input-Output Model

The Production and Market Supply Component

Thus far production of the various commodities is exogenous to the model. The component contains projections for acreage of the various field crops and for the number of animals in the various livestock enterprises and multiplies these levels by exogenously projected yields to get total projected output by commodities.

In order to get an idea about the seasonal distribution of labor requirements and product supply within the year, labor input and output supply are modeled in 10 day periods. A distributed delay function is fitted to observed distributions of planting and harvesting dates. The resulting aggregated seasonal labor profile is then compared to labor availability and used to draw conclusions with respect to mechanization needs or off-farm migration potential.

Given the total output $o_{jk}(t)$ of each crop, total sales $s_{jk}(t)$ are computed as the difference between output and farm consumption $c_{jk}(t)$ plus losses $\ell_{jk}(t)$.[1] (j = region; k = commodity).

[1] For convenience no index for the policy alternative (I, II, III or IV) will be listed.

(3.1) $$s_{jk}(t) = o_{jk}(t) - (c_{jk}(t) + \ell_{jk}(t))$$

The farm consumption is a function of gross income per capita $y_j(t)$ and average yearly producer price $p_k(t)$

(3.2) $$c_{jk}(t) = c_{jk}(0)\ [1 + e_{y_j} \frac{y_j(t)-y_j(0)}{y_j(0)} + e_{p_k} \frac{p_k(t)-p_k(0)}{p_k(0)}]$$

where

e_{y_j} = elasticity of consumption with respect to income

e_{p_k} = elasticity of consumption with respect to price

The Urban Demand Component

The urban per capita demand $g_k(t)$ for each commodity k is a function of prices, cross prices and per capita income disposable for consumption, subject to the budget constraint that total expenditure on consumption may not exceed the exogenously projected total income available for purchase of consumer goods.

(3.3) $$g_k(t) = a_k\, p_1^{e_{p_{k1}}}\, p_2^{e_{p_{k2}}} \ldots p_k^{e_{p_{kk}}} \ldots p_k^{e_{p_{k20}}}\, \bar{y}'(t)^{Ke_{y_k}}$$

k = 1, ..., 20

subject to

$$pop_2(t) \sum_{k=1}^{20} g_k(t)\, p_k(t) = pop_2(t)\, \bar{y}'(t)$$

where

p_j = commodity price for commodity j

$e_{p_{kj}}$ = elasticity of demand for commodity k with respect to prices of commodity j

e_{y_k} = elasticity of demand for commodity k with respect to income, computed as a function of the difference between current and target consumption levels

$\bar{y}'$ = per capita income, disposable for consumption as projected by a two sector model of the economy

K = parameter used to satisfy the budget constraint

pop_2 = urban population (persons)

commodities: 1 ... 19 = agricultural products
20 = industrial goods

The current consumption levels are computed in this model for prices that are either determined by policies or derived from supply/demand interactions, where the supply is predetermined and hence assumed to be fixed once the production decisions have been made for a given period.

Given total national supply s_k, the demand g_k at a certain price level, and marketing losses m_k, the market deficit d_k is computed as

(3.4) $$d_k(t) = g_k(t) - s_k(1-m_k)$$

The projected deficit in turn has to be imported or affects other grain management policies as determined in the grain management component.

The Grain Management Component [17].[1]

It is the goal of this component to evaluate the effects of alternative governmental food grain policies implemented upon the public and private marketing sectors. Policy instruments include direct market intervention, imports (rice) and import quotas and tariffs (wheat and feed grains) and the proportion of imports paid for in cash. Given as policy goals are the desired price levels and grain stock levels.

The basic policy instrument is the amount and timing of purchases and sales of rice and barley in domestic markets aimed at an adjustment of prices to given target prices. Using proportional and derivative control strategies simultaneously, the model provides for governmental market

[1] This component was not yet included in the published version of the model.

actions to correct for any discrepancies between actual prices and price changes on the one side and desired prices on the other side:

$$A_i(t) = -G3 \cdot CU \frac{pd_i(t)-p_i(t)}{pd_i(t)} - G4 \cdot CU \frac{d}{dt} [pd_i(t)-p_i(t)]/pd_i(t). \tag{3.5}$$

where

$A_i(t)$ is governmental sales if A_i is positive and purchases if A_i is negative

G3, G4 - policy control parameters

CU - average annual urban consumption

pd - desired price level

p - actual price level

The component determines imports of rice as a function of the difference between desired and actual government stocks and of the rate of change of this difference. Finally, it computes financial conditions like loan requirements and repayment schedules, cash foreign exchange deficit, costs for the gain management program etc.

Various distributed delay functions account for delays between import decisions and actual imports, time required in capital acquisition processes for storage facilities or repayment of loans.

In addition to the just mentioned system components, which include various routines for enterprise specific, regional and national accounting, the model uses projections from two independent models, representing the total population dynamics and the aggregate behavior of the Korean economy as a whole.

The Demographic Model [4].

The demographic model projects the growth of the rural and urban population, disaggregated by age and sex and -- in the case of the rural population -- by regions. It takes into account a future decline in birth rates resulting from family planning programs and a gradual decline in infant mortality and general death rates. The model also accounts for certain rural-urban migration rates, exogenously projected for the period until 1985. Hence, off-farm migration is not explicitly represented as a function of income differentials and non farm job opportunities, but is rather treated as a general trend affected by a variety of economic, sociological and psychological forces. The agricultural production component includes this agricultural labor force as an exogenous variable.

The National Input-Output Model

A highly aggregated two-sector model provides the urban demand component with exogenous projections of urban disposable income. The economy is divided into agriculture and nonagriculture and the model uses a 2 x 2 input output matrix to represent the technical interactions between both sectors.

3.3 A Recursive Programming Model of the Farm Firm Component

The purpose of incorporating a Recursive Linear Programming Model (RLP) into the existing system's model is to investigate how governmental price policies for inputs and products, how various research programs to increase yields and livestock performance or how different off-farm migration policies affect farmers' decisions with respect to resource allocation and introduction of new technologies.

A farm in Korea is typically a multiproduct farm, producing paddy rice, various vegetables and upland crops and possibly perennials like fruits and mulberry trees on the same farm. In addition to that, livestock production is expanding very rapidly. One also observes a transition from traditional technology using hand or animal drawn tools to modern and mechanized technology. This variety of enterprises and technologies competes for various constraints of physical resources like land of different categories, labor peak seasons, equipment capacities and cash capital. There are also behavioral limitations to changes of the farm organization. The complexity of this permanent choice problem led to the consideration of an activity analysis approach [15].

The application of activity analysis within a recursive decision system can be based on the experience with several similar models of aggregated supply response. Recursive linear programming models were first applied to agricultural development by DAY [6] to explain the historical change of agriculture in the Mississippi delta of the United States. Examples for models of individual farms are a study of STEIGER [23] which explains the transition from full-time to part-time farming in two German villages and of HEIDHUES [12] who projects the impact of various EEC policies on income and resource allocation in different farm types of West Germany. Similar problems concerning the EEC policy impacts on the Italian agriculture were treated by CIGNO [5] in an aggregate regional RLP model of production and investment response. Another example from German agriculture is a model of de HAEN [9] in which production and investment with main emphasis on mechanization are represented in a multiregional model and where each region is further disaggregated into farm size groups to account for aggregation problems. In the application to developing countries, DAY and SINGH [7] projected production and resource utilization for future periods, including an extensive validation of model results for a reference period. The model was applied to the Punjab as was another study by MUDAHAR [19]. Finally AHN [2] used a recursive programming approach to model agricultural production and investment by regions and farm sizes in Brazil.

All of these studies are based on what DAY and SINGH [7] call the strategic details of development. They may be summarized by saying that a model of the farm should reflect the following: 1. The multi-product and multi-process character of agricultural production; 2. the interdependence of farm household and firm decisions; 3. technological change; 4. asset fixity; 5. uncertainty; 6. learning and adoption; 7. non-farm linkages. For a more thorough discussion of the implication of these strategic details for the structure of microeconomic models it can be referred to the existing literature [7 , pp. 4-8; 9, pp. 7-12].

The Mathematical Model

For any given time period t the linear programming problem is given by

$$\text{(3.6)} \qquad \pi^*(t) = \max_{\bar{x}(t)} \langle \bar{z}(t), \bar{x}(t) \rangle$$

$$\text{s.t. } \underline{A}(t)\bar{x}(t) \leq \bar{b}(t)$$

$$\bar{x}(t) \geq 0$$

where $\pi^*(t)$ is the optimal value of the objective function.

In order to relate this decision problem for period t to previous decisions and to influences and informations from the environment, three basic sets of dynamic feedback functions are defined.

The first is a set of functions which relate the coefficients z_i of the objective function (expected payoffs) to past decision variables, shadow prices, and exogenous variables:

$$(3.7) \qquad \bar{z}(t) = z[\bar{x}^*(t-1), \ldots, \bar{x}^*(t-p), \bar{r}^*(t-1), \ldots, \bar{r}^*(t-p), \bar{v}(t)]$$

where

$\bar{r}^*(t)$ = vector of optimal dual values (shadow prices) of constraints
$\bar{v}(t)$ = vector of exogenous variables
$*$ = optimality
p = maximal length of a lag

The second is a set of functions for the elements of the constraint vector

$$(3.8) \qquad \bar{b}(t) = b[\bar{b}(0), \bar{x}^*(t-1), \ldots, \bar{x}^*(t-p), \bar{r}^*(t-1), \ldots, \bar{r}^*(t-p), \bar{v}(t)]$$

The third is a set of functions for the elements of the input-output matrix

$$(3.9) \qquad \underline{A}(t) = A[\bar{x}^*(t-1), \ldots, \bar{x}^*(t-p), \bar{r}^*(t-1), \ldots, \bar{r}^*(t-p), \bar{v}(t)]$$

3.4 Linkages Between the General System's Model and the Recursive Programming Model

This chapter contains a brief summary of the main interactions between the two models. A detailed description of the model, the source of the various variables and the programming routines can be found in Chapter 4 and in Appendix A.

Generally the linkage can be described by the following mathematical model:[1]

[1]See also Chapter 3.2.

The General System's model is basically block recursive, with one block being a Linear Programming Model. The inputs (exogenous variables) to this LP-component are either lagged outputs from the LP and other components of previous periods or they are outputs from components being computed earlier in the same period or they are projected exogenously prior to the simulation run. This dynamic feedback holds for the objective function, the constraint vector and the input-output matrix.

Assuming that the overall vector of endogenous variables $\bar{x}(t)$ can be split into subvectors $\bar{x}_i(t)$:

$$\bar{x}(t) = \begin{bmatrix} \bar{x}_1(t) \\ \vdots \\ \bar{x}_n(t) \end{bmatrix}$$

the complete system can be represented in the following form:

$$\bar{x}_1(t) = g_1 [\qquad \bar{x}(t-1), \ldots, \bar{x}(t-p), \bar{y}(t), \bar{v}(t]$$

$$\bar{x}_2(t) = g_2 [\bar{x}_1(t), \qquad \bar{x}(t-1), \ldots, \bar{x}(t-p), \bar{y}(t), \bar{v}(t]$$

$$\vdots \qquad\qquad \vdots$$

$$\bar{x}_{m-1}(t) = g_{m-1}[\bar{x}_1(t), \ldots, x_{m-2}(t), \qquad \bar{x}(t-1), \ldots, \bar{x}(t-p), \bar{y}(t), \bar{v}(t]$$

$$\bar{x}_m(t) \quad \varepsilon \ \{\bar{u} | \max_{\bar{u}} < \bar{z}(t), \bar{u} > ; \underline{A}(t)\bar{u} \leq b(t); \bar{u} \geq 0\}$$

$$\vdots \qquad\qquad \vdots$$

$$\bar{x}_n(t) = g_n [\bar{x}_1(t), \ldots\ldots\ldots\ldots, \bar{x}_m(t), \ldots, \bar{x}_{n-1}(t), \bar{x}(t-1), \ldots, \bar{x}(t-p), \bar{y}(t), \bar{v}(t]$$

where

$$\bar{z}(t) = h_z[\bar{x}_1(t), \ldots, \bar{x}_{m-1}(t), \bar{r}^*(t-1), \ldots, \bar{r}^*(t-p),$$
$$\bar{x}(t-1), \ldots, \bar{x}(t-p), \bar{y}(t), \bar{v}(t)]$$

$$\bar{b}(t) = h_b[\bar{b}(0), \bar{x}_1(t), \ldots, \bar{x}_{m-1}(t), \bar{r}^*(t-1), \ldots, \bar{r}^*(t-p), \bar{x}(t-1), \ldots, \bar{x}(t-p), \bar{y}(t), \bar{v}(t)]$$

$$\underline{A}(t) = H[\bar{x}_1(t), \ldots, \bar{x}_{m-1}(t), \bar{r}^*(t-1), \ldots, \bar{r}^*(t-p), \bar{x}(t-1), \ldots, \bar{x}(t-p), \bar{y}(t), \bar{v}(t)]$$

with:

$\bar{x}_1(t), \ldots, \bar{x}_m(t), \ldots, \bar{x}_n(t)$ sub-vectors of endogenous variables of the respective system components with $\bar{x}_m(t)$: vector of optimal primal activity levels in the LP component

$\bar{u}$ - vector of primal activity levels of LP
$\bar{y}(t)$ - vector of exogenous variables
$\bar{r}^*(t)$ - vector of optimal levels of the dual variables of the LP component
$\bar{z}(t)$ - vector of objective function coefficients of the LP component
$\underline{A}(t)$ - coefficient matrix of the LP component
$\bar{b}(t)$ - constraint vector of the LP component
$\bar{v}(t)$ - vector of policy variables

Actually the whole system becomes the model of a recursive decision system, where the LP component represents the farm-firm component of the agricultural sector and the other components describe the physical and institutional environment, in which the firms operate and in which farmers derive their decisions.

In the Korean model this environment is represented by: 1. The market component from which prices are fed back as informations into the farm-firm component. The market model itself is receiving inputs from a national input-output model which projects total food expenditures of the urban population. 2. The demographic model feeds projected agricultural labor force as physical constraint into the farm-firm model. 3. The production component provides the farm-firm model with projections for input-output coefficients, prices for inputs and the age distribution of perennial field crops like orchards. 4. Finally the farm-firm model receives from other components informations on projected change in land capacities due to land reclamation, upland development and urban expansion.

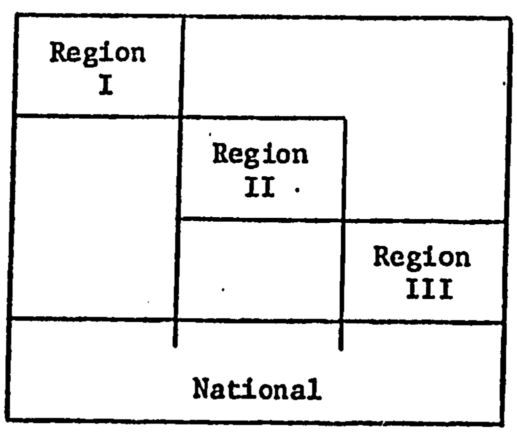
The main outputs of the farm-firm component (LP) which are recursively linked to the respective other components are production levels, requirements for capital and other inputs including labor, machinery investment, import requirements for feed and gross income from agriculture. Hence the combination of both main components (SIM and RLP) within a General System's Approach makes it possible to view agricultural production and supply response as part of a more comprehensive system, i.e., as an interacting component of the whole economy and society.

The LP model is solved once every year. The time increment for other components of the whole model may be different.

4. Basic Assumptions and Model Formulation[1]

4.1 One Periodic Multiregional Activity Analysis

The LP component for each year is block diagonal with one block for each of the three regions:



[1]For a complete model description see Appendix A.

This structure makes the modeling of interregional competition possible. In the current version of the model, there are three overlapping constraints for all three regions. Two stand for the politically fixed national quota of raw silk and tobacco production. The third is a restriction for feed grain imports. All other constraints are repeated in each region.

So far no further disaggregation into farm size groups has been considered. Due to a land reform and a legal limitation of the maximal farm size in acres in Korea, a distinction of different farm size groups did not seem necessary.

Following is a description of the structure of one regional matrix.

4.1.1 Activities

The activities of the model are: 1. Production of field crops, distinguished by type of technology; 2. Production of livestock products; 3. Planting of orchards and mulberry fields; 4. Investment in farm machinery; 5. Feed grain imports; 6. Various transfer activities.

The definition of the crop and livestock commodities of the existing simulation model is maintained in the definition of the LP-activities with only one exception. The LP activity "summer grains" is composed of two crops of SIM, "other grains" and "pulses", the weighting coefficient being the actual proportion of the respective acreages in the past. In addition to the products of SIM, the LP model contains production activities for intensive and traditional use of pasture land. The improvement of the mostly wild pasture, at the present time collectively used in the villages, by cultivation and fertilizer application is an important precondition for the expansion of the cattle and dairy herd.

Each crop production activity includes land preparation, planting, cultivating, fertilizing, harvesting and transporting. It also includes the supply of potential feed (as a coefficient) and of cash product. The technology may either be traditional, i.e., using hand and animal tools, or mechanized with a 10 hp-powertiller including the necessary attachment. In the case of rice production there is a third separate technology: transplanting of rice by rice transplanter. Although a binder as attachment to the tiller and a rice transplanter are not yet common in Korea, they are considered as new technologies because they are frequently used in Japan.

The livestock activities are dairy, Korean cattle, hogs, eggs and broiler production. They are expressed in units of one mature female breeding animal.

The activities for planting of perennial crops are investment in farm capital. They include the effects of intercropping with upland crops like grains and forage for the first 3 to 5 years after planting.

4.1.2 Constraints

The constraints, denoted by $y_i(t)$ in the following section, for each region include land capacities for paddy, summer upland and winter upland, where winter upland is a subset of paddy and summer upland. They include three labor peak seasons, three machinery peak seasons for tiller and one for rice transplanter. There are limitations for the current herd size of the various livestock activities. Two constraints are introduced to limit the current size of mature orchards and mulberry fields. Further there are flexibility constraints for several major products and adoption constraints for new technology. Finally the model includes several balance equations for feed inputs.

Neglecting the production of upland crops on paddy land, equation 1 guarantees that the total area planted with paddy rice by different technologies does not exceed the projected area y_1 of paddy land in a given region:

(4.1) $$\sum_{j \epsilon RT} x_j(t) \leq y_1(t)$$

RT: set of paddy rice production activities with different technology.

Two further equations (y_2 and y_3) express the capacities of summer and winter upland. In several cases (like industrial crops, vegetables or potatoes) a certain historical proportion is used to distribute the total area per activity unit among winter and summer crops. The upland capacity is reduced by the area newly planted with fruit (j = 33) or mulberry (j = 35) trees in that year.

(4.2) $$\sum_{j \epsilon P_i} a_{ij}x_j(t) \leq y_i(t) - a_{i33}x_{33}(t) - a_{i35}x_{35}(t)$$

i = 2,3
P_2: set of all activities requiring summer upland
P_3: set of all activities requiring winter upland

This formulation includes the implicit assumption that all land can be mechanized and that there are no differences in labor requirements or input-output ratios for different locations within a region. This simplification seemed necessary due to data shortage and computer time limitations.

An empirical analysis of seasonal labor profiles for current cropping patterns led to the definition of three labor peak seasons (equations 4, 5, 6): March, June and October:

(4.3) $$\sum_{j \in P} a_{ij} x_j(t) \leq y_i(t)$$

$i = 4,5,6$ (labor peak seasons)

P: set of all crop and livestock production activities

Equations 7 to 10 define machinery capacities (tiller plus attachment in three peak seasons and transplanter capacity) which hold for all crop activities with mechanized technology. They can be expanded by investment activities, defined for machinery aggregates:

(4.4) $$\sum_{j \in T} a_{ij} x_j(t) \leq y_i(t) + a_{i\ell} x_\ell(t)$$

$i = 7, \ldots, 10$

T: set of all crop activities requiring mechanization

$a_{i\ell}$: capacity (hours) per season i provided by investment activity ℓ

Equations 11 to 14 are balance equations for barley, for potatoes (where the model determines the proportions used for human consumption and feed purposes), and for feed concentrates and rouphage.

Equation 15 represents the projected pasture land capacity, utilized by a fertilizer intensive and extensive grass production activity. Further three constraints (16, 17, 18) account for the current potential herd sizes of dairy cows, Korean cattle and sows and hence represent a physical upper limit on the expansion of livestock production given certain import rates determined by policy variables.

Equations 19 and 20 guarantee that orchards and mulberry fields -- once they are planted -- are cultivated and harvested in the full amount of their capacity.

(4.5) $$x_j(t) = y_i(t)$$

$i \in$ {set of constraints for existing fields with mature trees}
$j \in$ {set of activities for production of fruits and raw silk}

Equations 21 to 27 are behavioral constraints (flexibility and adoption constraints) to account for safety and cautiousness behavior of farmers. The main idea hereby is the assumption that farmers are not willing to deviate by more than a certain proportion from past production and technology patterns.

The notion of flexibility constraints as commonly used in recursive programming approaches to agricultural development, is commonly introduced into the model by a set of upper and lower limits for each product. Using prior information on future trends in prices and technologies in Korean agriculture and being restricted by limited computer space for this model component, we had to exclude those flexibility constraints which would most likely not hold or where (like in the case of expanding the dairy or hog production) abrupt deviations from the past were technically not feasible anyway. Remaining was a set of upper bounds:

(4.6) $$x_j(t) \leq y_i(t)$$

$j \in$ {set of activities for vegetable production and planting of fruit trees}
$i \in$ {set of upper bounds for vegetables and planting of fruit trees}

and of lower bounds:

(4.7) $$x_j(t) \geq y_i(t)$$

$j \in$ {set of activities for wheat, barley, hog, dairy production}
$i \in$ {set of lower bounds on wheat, barley, hog, dairy production}

Should the assumptions with respect to the effectiveness of the flexibility region not be true for alternative policy runs and unacceptable fluctuations (on the side of the farmers) in the unrestricted directions occur, then further flexibility constraints will be considered.

Investment in tiller plus attachment and in rice transplanters is restricted to a maximum number of aggregates per year to account for adoption behavior of farmers in the transition process on the one side and for limitations of the supply capacities of machinery industries on the other side.

Governmental policies restrict the production of tobacco and raw silk as well as the amount of feed grain imports on the national level. The interregional competition for participation in these quotas is represented in the model by overall national constraints for land allocation to tobacco and new mulberry fields and for feed grain imports:

(4.8) $$\sum_{k=1}^{3} \sum_{j \in A_i} a_{ij}^k x_j^k(t) \leq y_i(t)$$

$i \in N$ (set of national constraints)

k - regions

A_i: (set of activities requiring the national constraint i)

4.1.3 Objective Function

The model assumes that farmers try, within the limits of the current physical and institutional constraints, to realize those combinations of enterprise and activities which maximize the expected income without running an unbearable risk of loosing a basis for the family's subsistence. It is assumed that the Korean farmer accounts for this uncertainty by restricting the expansion of new production enterprises or the introduction of new technology to certain maximal deviations from his past production and technology pattern. This means that even though the present profitability of a certain new activity may seem favorable, it is unlikely that a farmer would immediately expand that enterprise at a large rate. This behavioral limitation of the decision space is accomplished in the model by the introduction of flexibility and adoption constraints.

It is assumed that farmers make their decisions within a relatively short planning horizon. Uncertainty about events which lie further in the future lets them hesitate to stick to one long term plan. Instead they repeat the decision process frequently (in the model yearly for allocation and investment), each time taking into account new information collected since the last period. Although the assumption of a one year planning horizon may seem inadequate for decisions on investments such as orchards or machinery, it seemed to be necessitated on operational grounds. With computer capacity becoming less scarce, it would seem desirable to use a multiperiodic model to account for longer term expectations where they can be assumed. Parameters for periods later than the presently projected period would then be repeatedly revised as new informations are collected by the farmer (Rolling Plan Models) [20].

The actual coefficients of the objective function represent expected yearly average gross returns minus variable costs, including non cash items like interest costs for working capital or depreciation.

4.2 Dynamic Feedback and Exogenous Variables

In order to account for the dynamic properties of the sectoral adjustment and growth process, a dynamic feedback operator is defined which relates the values of the objective function coefficients, of constraints and of matrix coefficients to preceeding LP solutions, to variables being computed in other parts of the simulation model and to exogenously projected variables.

4.2.1 Objective Function Coefficients

Profit expectations are assumed to be the actually realized figures lagged by one year. They are generally a function of previous yields, prices for outputs and variable inputs and input quantities, all of them being projected by various components of the simulation model.

For perennial livestock activities the objective function coefficient includes the yearly average net returns during the mature production phase minus proportional replacement costs plus proportional salvage returns.

Similarly the objective function coefficient for production from existing orchards and mulberry fields is computed as the average, yearly net return during the mature phase.

Farmer's decisions to replant old orchards or mulberry fields or to expand the existing capacity are generally based on their current profits. Neglecting discount rates, it is assumed that the net profit, $z_j(t)$, from new planting can be represented by the lagged dual value of the existing fields, r_i^*, corrected for the fact that there is a phase of N' years where the trees don't have yields yet, minus depreciation and interest costs for the acquisition capital for new plants (a_j) and plus net proportional profits from intercropping p:

$$z_j(t) = \frac{N_i - N_i'}{N_j} r^*_{i_j}(t-1) - a_j(t)\ [1/N_j + 1/2\ c(t)] + \frac{N_i'}{N_j} p_j(t) \tag{4.9}$$

$j \in$ {set of activities for planting of fruit trees and of mulberry bushes}

$i_j \in$ {set of constraints for the respective existing fields}

N - total life time (years)

c - interest rate

The costs for machinery investment are composed of interest costs and depreciation, assuming a salvage value after N_j years of 10% of the acquisition price p_{aj}:

$$z_j(t) = -.9\ p_{aj}(t)\ [1/2\ c(t) + 1/N_j] \qquad (4.10)$$

$j \varepsilon$ {set of machinery investment activities}

In the case of investment in power tillers these costs are reduced by the additional profits which result from more efficient fattening (shorter life time with the same final weight) of draught animals, provided the initial herd of draught cattle is not yet totally replaced by tillers.

4.2.2 Farm Resources

Farm resources comprise land, labor, machinery, pasture land, orchards, mulberry fields and livestock herds. Total land and labor capacities are exogenous variables for the RLP component, originating from exogenous projections and from the demographic model respectively. In order to get capacities available for allocation decisions, pre-occupied areas (newly planted fields) or pre-occupied labor (for intercropping under pre-mature orchards and mulberry fields) are subtracted:

land:

$$y_i(t) = y_i(t-1) + v_i(t) - \sum_{j \varepsilon R} b_{ij} x_j(t-1) \qquad (4.11)$$

R: set of planting activities for perennials

$i \varepsilon$ {set of land constraints}

v_i: exogenous change in land capacity i

labor:
(4.12)

$$y_i(t) = \ell(t) \cdot b_i(t) - \sum_{j \in R} \sum_{s=1}^{N'_j} b_{ij} x_j(t-s)$$

$i \in W$: set of labor constraints

ℓ projected agricultural labor force

b_i - capacity in hours per season and worker

N'_j - length of pre-mature phase (years) of perennial crop activity j

The capacity of machinery j is expressed in hours per season (α_{ij}) and is a function of investment in previous years. Depreciation is approximated by dividing the average life time S_i into three segments (S_i^k) with increasing rates of depreciation.

(4.13)

$$y_i(t) = \alpha_{ij}[S_i^1 \lambda_i^1 \sum_{s=1}^{S_i^1} x_{j_i}(t-s) + S_i^2 \lambda_i^2 \sum_{s=1}^{S_i^2} x_{j_i}(t-s) + S_i^3 \lambda_i^3 \sum_{s=1}^{S_i^3} x_{j_i}(t-s)]$$

$i \in M$: set of machinery constraints

$j_i \in I$: set of investment activities

Pasture land, although in most cases collectively used in the villages, is treated as a farm resource in the model, the capacity being exogenously projected in a study of upland development [24].

The technically maximal herd sizes of female breeding animals $y_{i \in V}$ are computed as a function of last year's actually utilized herd x, of the potential net addition from the young female herd and of imports, determined by policy:

(4.14) $$y_i(t) = x_{j_i}(t) + \beta_i x_{j_i}(t-S_j) + \delta_j(t)$$

$i \varepsilon V$: set of capacities for livestock herds

$j_i \varepsilon VP$: set of livestock activities

β net rate of potential herd expansion per unit of activity

δ imports

S_j: maturation time (years) of young female animals

The capacity of fields with perennial crops is equal to the sum of hectares presently in age cohorts 2-4, derived from a distributed lag model with four production cohorts, contained in the existing simulation model. The model is described elsewhere [1]. Assuming that the maturation delays in each cohort are stochastic and that the distribution of the individual delays is known, it approximates the maturation process in each cohort by the following linear differential equation:

(4.15) $$a_k \frac{d^k u_i(t)}{dt^k} + a_{k-1} \frac{d^{k-1} u_i(t)}{dt^{k-1}} + \ldots + a_1 u_i(t) = v_i(t)$$

where v_i denotes the number of hectares entering the age cohort i and u_i denotes the lagged variable leaving the age cohort i (and entering cohort i+1 or going out of production).

4.2.3 Flexibility and Adoption Constraints

As discussed earlier, some flexibility constraints are imposed on the year to year changes in land allocation and livestock production patterns, thus defining a safety zone for the current production decisions. Both, the upper and the lower bounds are a function of the previous year's optimal level of the decision variables. The sets of upper and lower bounds are defined as follows:

upper bounds:

(4.16) $$\sum_{j \epsilon P_{j'}} x_j(t) \leq y_i(t) = (1+b_i) \sum_{j \epsilon P_{j'}} x_j(t-1)$$

$i \epsilon B^u;\ j' \epsilon J'$

lower bounds:

(4.17) $$\sum_{j \epsilon P_{j''}} x_j(t) \geq y_{i'}(t) = (1-b_{i'}) \sum_{j \epsilon P_{j''}} x_j(t-1)$$

$i' \epsilon B^\ell;\ j'' \epsilon J''$

where $P_{j'}$, $P_{j''}$ are sets of activities for production of commodity or commodity group i and i' respectively; B^u, B^ℓ are sets of upper and lower bounds respectively; J', J" are families of sets of activities with upper and lower bounds respectively (to each $i \epsilon B^u$ and $i' \epsilon B^\ell$ there correspond exactly one $j' \epsilon J'$ and $j'' \epsilon J''$) and b_i, $b_{i'}$ are maximum rates of expansion or contraction of last year's production levels.

In accordance with most of the methods suggested to quantify the flexibility coefficients [18], we estimated the b_i and $b_{i'}$, from historical year to year changes. After separating the observed relationships

$$x_j'(t) = (1+\beta_j)x_j'(t-1)$$

into positive and negative β_j^+ and β_j^- we computed as a first approximation the b's as an average of the three biggest change rates in the last ten years:

(4.18) $$b_i = 1/3 \sum_{s \epsilon M} \beta_j^+(s)$$ M: set of indices for three years with the highest β_j^+

(4.19) $$b_{i'} = 1/3 \sum_{s \epsilon M'} |\beta^-(s)|$$ M': set of indices for three years with highest absolute β_j^-

If safety considerations played a role in determining farmers' decisions in the past at all, then the biggest change rates in production patterns rather than average rates would indicate the size of those behavioral constraints.

Another set of constraints is used to prevent drastic increases in stocks of specific machineries, an assumption which seemed particularly important in the current process of transition from mostly hand and animal power to mechanized production. Assuming that farmers relate their net investment decisions with a rate λ_i to the stock of that investment good which they are currently using and given a depreciation rate α_i, one gets maximum gross investments x_j from the following inequality:

$$x_j(t) \leq y_i(t) = \lambda_i \sum_{\ell_i \varepsilon T_i} x_{\ell_i}(t-1) + \alpha_i y_i(t-1)$$

$$j \varepsilon I_g;\ i \varepsilon IC$$

where to each $j \varepsilon I_g$ there corresponds exactly one $i \varepsilon IC$. I_g is a set of gross investment activities. IC is a set of investment constraints and T_i is the set of mechanized production activities using investment good i.

Finally it should be mentioned that the notion of flexibility constraints treats farmers' uncertainty and risk behavior only implicitly and is used as a compensation for the fact that the model does include all those economic and psychological factors determining behavior. An alternative way of explicitly incorporating some of those factors will be investigated later, following suggestions of BOUSSARD and PETIT [3] to represent farmers' notion of risk as single valued expectations of maximal gains and losses of each activity within a "focus loss constrained programming approach".

5. Problems of Data Collection

The quantification of the model made it necessary to use quite diverse sources of data. The values of the input-output coefficients in the LP component are generally based on cross-sectional data, the parameters of the dynamic feedback functions as well as projections of exogenous variables basically derived from time series data. However the lack of statistical observations and the necessity to consider technological change so far unexperienced in Korea, make it inevitable to rely also on individual judgements, experiments or technical engineering coefficients.

An initial set of data for which the model is presently tested, is presented in Appendix B. Like the model structure itself it will certainly have to be revised. Some of the problems with respect to reliability and availability of data which will need some further research are the following: One difficulty arises from the fact that for some groups of coefficients a variety of studies and estimates are available which differ remarkably from each other. Sensitivity analysis with respect to the model parameters based on those data will be necessary to evaluate their importance and possibly derive conclusions for further primary data collection. Another problem lies in the lack of regionally disaggregated data. Unless better informations on regional production functions are available, the model can hardly determine regional specialization in production patterns. This refers particularly to input-output relationships for livestock and feed crop production, which will possibly be increased to a considerable extent in the years ahead. Finally it seems necessary to investigate the possibilities of changing the labor inputs over time for production activities with given machinery sets to account for the commonly observed fact that farmers react to the continuously increasing scarcity of labor by simplifying certain tasks, organizing task combinations and sequences more effectively, consolidating fields, etc. To leave the labor requirements for given mechanized processes constant over time would possibly be unrealistic and lead to an overestimation of labor requirements in agricultural production.

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