# MODELLING THE IMPACT OF SMALL FARM MECHANIZATION

Philippine Institute for Development Studies
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# FOREWORD

Agricultural planners, policymakers and research administrators are continuously called upon to make judgments regarding priorities for investments in rural development and research. The soundness of these decisions is determined by a combination of insight and information. Ideally, decision-makers will have both in abundance.

Mathematical models can extend both the insights and the information available to the decision-maker. Building a mathematical model with a basis in reality requires data describing both the past and present state of the economic and resource environment. To synthesize and interpret the results of such models requires insight, imagination and a reasonable level of mathematical expertise.

The rationale for using models is, however, not to relive the past in mathematical abstraction but to develop a sound understanding of the interdependent nature of economic and technical relationships and to use these relationships to extrapolate from the present to the future. Adjusting policy parameters allows decision-makers to examine the impact of a wide range of options on resource use, output or other development objectives.

The papers contained in this monograph were designed to examine the impact of agricultural engineering technologies on production, employment and rural incomes. The first three focus on macro issues; a fourth addresses the choice of technique question at the farm level. The two general equilibrium models from the Philippines (Ahammed and Herdt) and from Indonesia (Ahammed and Duff), examine the effects of alternative mechanization policies on output, use of labor, total income and income distribution by farm and income group. This class of model measures both the direct and indirect impact of technological change and explicitly quantifies the multiplied effects of the consumption/production linkages between various sectors of the economy. These general equilibrium models are valuable tools in assessing the impact of various policy options.

The Webster—Herdt model is a simulation approach. This model is distinguished from the general equilibrium model by its non-deterministic nature and the form of the underlying equations. Structural equations, constraints and objective functions may all be nonlinear. A major limitation of this class of model is its failure to explicitly capture interdependencies resulting from production and consumption linkages. Despite this constraint, simulation provides a flexible means to examine *ex ante* projections over a range of policy alternatives.

The Rahman—Wicks paper describes a mixed integer programming model. This technique is widely used in both management and research. The present model incorporates discrete resources such as machines and is used to assess the economic viability of alternative equipment combinations for small-scale agricultural applications.

Each model is part of a study of the Consequences of Small Farm Mechanization on Production, Employment and Income in Selected Countries of Asia sponsored by the International Rice Research Institute in collaboration with research institutions in Indonesia, Thailand and the Philippines. The Philippine Institute for Development Studies has taken the lead in communicating the results of this research to development practitioners. Financial support for the study and publication of these results has been provided by the United States Agency for International Development.


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# MODELLING INCOME DISTRIBUTION EFFECTS WITH A COMPUTER–ASSISTED POLICY MODEL OF THE PHILIPPINE RICE SECTOR

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Policymakers and researchers often phrase their concerns quite differently. Policymakers grapple with specific, empirical problems while researchers usually focus on longer run, more general questions, often developing theories to explain observed events. The model described here is a deliberate effort to bridge the gap between theoretical and empirical research on policies affecting growth and distribution. Part of the gap occurs because empirical work is based on history, and in a world of rapid change, historical experience is described in obsolete prices within a structure that may have ceased to exist by the time research results reach a policymaker, thereby limiting the value of empirical research. Theoretical analysis, on the other hand, is fraught with assumptions that do not reflect the real world. Dynamic analysis that looks at the course of future events suffers from all these problems to a greater extent than static economic description or measurement. However, because the future will always be there, it holds an inescapable importance.

The model described in this paper is an attempt to design a policy analysis tool that is forward looking, dynamic and empirically based on sound theoretical ideas. To the extent that it is successful, it can be a useful tool for evaluating alternative policy actions designed to affect Philippine food security through rice production and consumption. The general approach may be useful for evaluating the effects of policy actions of other countries as well, especially those in which a single commodity plays a central policy role as rice does in the Philippines.

Food security consists of two related but distinct goals — — the ability to "ride out" short term fluctuations in supply and the ability to ensure that the trend rate of production increase is at least as rapid as the trend rate of demand increase. A great deal of attention has recently been focused on policies directed at short term fluctuations — — buffer stocks, food funds, emergency import facilities, etc. (Chisholm and Tyers 1982 ). Studies have found that it is more efficient (less expensive) for countries to rely on the international market than to operate large buffer stocks (Valdes and Siamwalla 1981 ), and that "international cooperation in the administration of a grain reserve scheme and in the allocation of costs involved in acquiring and holding stocks among the beneficiary nations" is preferable to individual country stocks (Konandreas and Schmitz 1978 ). The other aspect of food security — — ensuring an adequate trend rate of production increase — — requires more analytical attention.

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The trend rate of increase in demand for food will be affected by the distribution of income. This is so because low income consumers have different income elasticities of demand for various commodities than higher income consumers, and alternative policies may affect the distribution of income (Mellor 1976 ). Thus an adequate framework for evaluating alternative food policies must reflect both the availability of food and the distribution of income. This requires a model that will predict whether (a) enough food is available so that all can consume adequate quantities, and (b) all have enough income so they can purchase food in adequate quantities. This paper reports on a quantitative model that generates such information.

The model projects the demand and supply for rice and calculates the likely impact of policies on income distribution among five income classes with. different food demand patterns and different agricultural resource ownership patterns. The model is used to evaluate various combinations of policies for their efficiency in ensuring that production keeps pace with demand and for their impact on the income of each economic class.

Because of data limitations and the complexities of doing otherwise, the production side of the model is confined to rice. This limitation is justified by the importance of rice in the Philippine diet and agricultural production system. Substitution of other foods for rice is limited, and rice fields can be used for other crops with difficulty. In addition, rice is the dominant political commodity, figuring prominently in discussions of national economic problems, leading the parade of accomplishments enumerated by political figures or providing an issue capable of provoking urban disorders. Rice prices are a visible indicator of government's concern for the welfare of consumers and farmers. For these reasons, rice provides a challenging focus for analysis of food and agricultural policies in the Philippines and in other Asian countries. Still, rice is only part of the picture, but a successful rice model would provide a base for more complete agricultural policy models.[1/]

Concerns with rice arise from two dominant characteristics of the rice situation — excessive fluctuations in output and hence price, and uncertainty about long run trends. Short run price fluctuations create uncertainty about longer run trends in output and leave policymakers in a quandary over the appropriate level and timing of investments in irrigation, fertilizer, extension services and research. Several years of production equal to or in excess of needs reduce the urgency for agricultural production increases and tend to postpone or eliminate investments with long gestation periods, thereby creating conditions leading to future shortages.

The prototype policy analysis model discussed in this paper has been developed to explore the issues outlined above. It is designed to integrate short, medium, and long run policies affecting the rice sector, show the impact of one on the other, and show how separate analytical subsystems can be integrated into a model that can simultaneously evaluate the impact

1/ A model similar in some respects to the one discussed herein but with a multi-commodity production side is presented by Quizon and Binswanger for India.

of policy initiatives on all of the subsystems. It can help distinguish between short run fluctuations in output and long run trends. It can be used to evaluate the likely impact of alternative investments needed to maintain a desired rate of growth in rice production and to determine the relative efficiencies of various policies affecting developments in the fertilizer, irrigation and technology development sectors.

It is obvious that these policy areas are interrelated. A shortfall in production can be met by imports, by stocks of grain held within a country, by substituting another commodity for rice, or by rationing the available rice. Production can be increased by using additional fertilizer. However, since irrigated land is more productive than non-irrigated land, irrigation can therefore "substitute" for fertilizer. Irrigation capacity generally takes several years to develop while fertilizer can be imported and applied in a short period. Both fertilizer and irrigation are used with greater efficiency after farmers have learned to use them while inherent maximum level of productivity is determined by the available technology. The enumerated interrelations are so obvious as to be trivial. However, it is a good deal easier to recognize them than to quantify them. We have attempted to quantify them in the model described in this paper.

The present model should be regarded as a prototype from which useful developments might flow. Some of the ideas in it are applicable to many countries in Asia; the data are for the Philippines. Indeed, insofar as research needed to generate some of the data is still underway, the estimates of certain parameters and relationships are conjectural. With firm estimates of data, the model can assist Philippine policy agencies to do better planning and policy analysis. With appropriate data and modifications, the model might prove useful for other countries as well.

## AN OUTLINE OF THE MODEL

The model is used to examine the effect of alternative actions in a simulation of the Philippine rice economy. The simulation is built from equations and relationships that describe the structure of the rice economy. In the model (as in the economy), rice prices are determined from the interaction of supply and demand, demand is a function of income, income is a function of resource ownership, and behavioral statements are based on the assumption that individuals are motivated by economic forces in production and assumption. Certain factors are assumed to be controlled or influenced by government policies — — fertilizer supplies, fertilizer prices, the availability of machinery and the rate of expansion in irrigated land. With some prices and quantities determined by market forces and others by government policies, the model attempts to represent the blend of market and non-market forces that prevails in the Philippine rice sector.

Figure 1 indicates in very gross outline the main components of the model. Rice production resources (land, labor and farm machinery) are controlled by the three farm classes — — small farmers (SF), larger farmers (LF) and landless laborers (LL). Two additional classes derive income

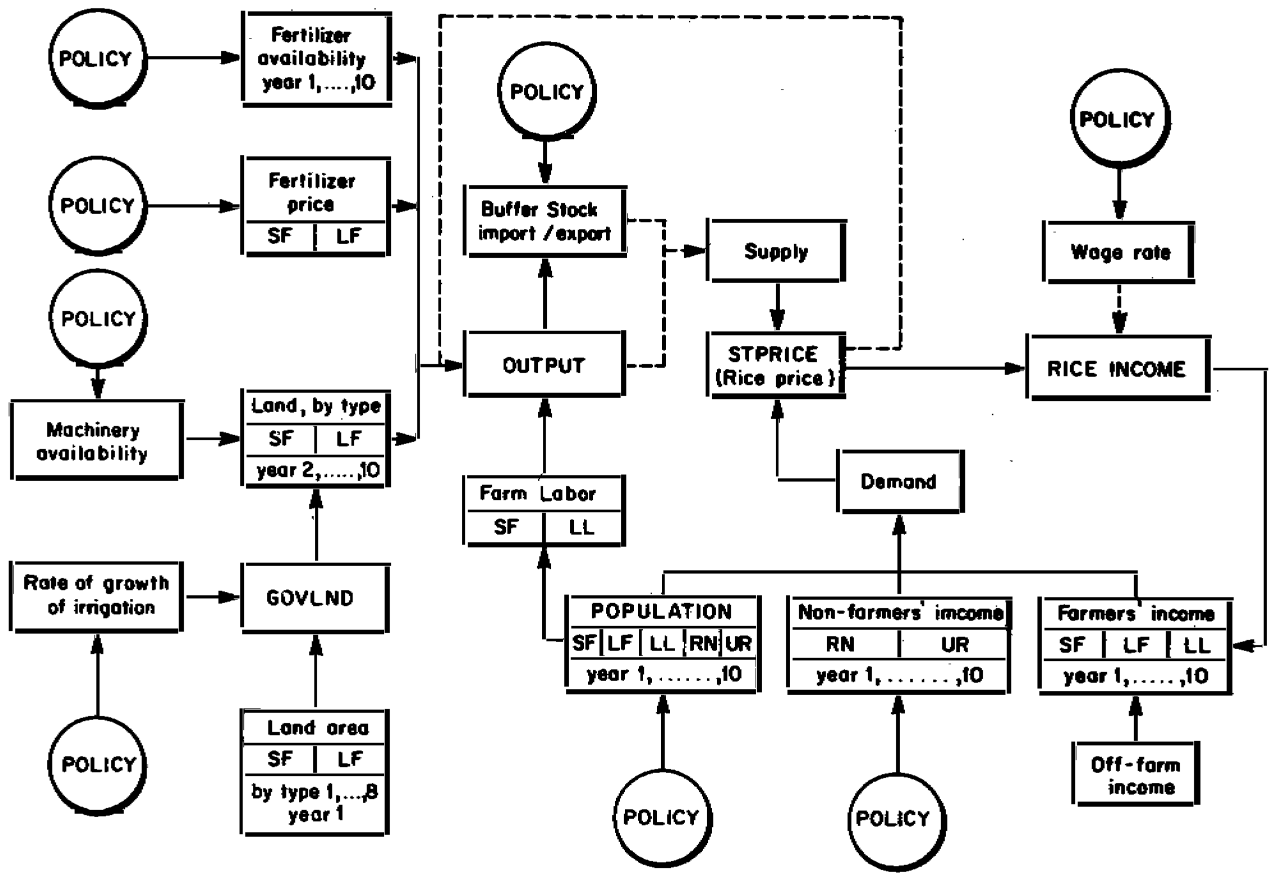


Figure 1. Rice Policy Model

from the non-farm sector — — rural non-farm (RN) and urban (UR). Eight land types are included — — four each in the wet and dry seasons. Irrigation investment "creates" better quality land from poorer quality land. Total rice land area is fixed, but irrigation increases the effective area through increasing intensification. The amount of land of each quality owned by each economic class is specified.

Fertilizer supply is exogenously determined by government policy. Fertilizer demand is endogenously determined by the productivity of fertilizer on the several types of land and the amount of land in the various types.

The availability of farm machinery is determined by government policies. The impact of the adoption of six machines can be evaluated: four-wheel tractors, two-wheel tractors, small threshing machines, larger axial flow threshers, 4" diameter irrigation pumps and rice transplanters. Each can have an impact on labor use and rice production.

The price of rice is determined endogenously through an iterative procedure that finds the price at which the supply in a given period is equated to the demand. Alternatively, the rice prices may be fixed exogenously and the excess quantity supplied or demanded calculated. The second procedure implicitly assumes exports of the necessary quantity are possible. The rice demanded by each income class is a function of the market rice price and the income of each class. Individual class demands are aggregated to obtain total demand. Income-class-specific income and price elasticities provide feedback from income distribution effects to the market rice price.

Incomes of small farmers, large farmers and the landless are determined by their ownership of productive resources — land, labor and machinery. Income in the non-farm sector and from non-farm source is exogenous.

The total value of rice produced is allocated among the factors of production as follows: The returns to fertilizer and other inputs go outside the agricultural sector. Land rent goes to owners of land. Wages go to suppliers of labor. Payments to capital go to the owners of capital. Factor prices are determined in different ways: Fertilizer's price is a policy variable as is the price of machinery, wages are assumed to be fixed in terms of quantity of grain as is land rent. The residual income after paying these costs remains with the farm operators.

## POLICY INSTRUMENTS AND COSTS

Each of the policy instruments available to government has an associated cost. Policy instruments include fertilizer price and availability, irrigation investment, farm machinery numbers and prices, rice imports and exports, and government rice purchases and sales to consumers. Rice price control is achieved indirectly through policies affecting production or directly through annual trade and buffer stock operations.

*Fertilizer Policies.* Domestic fertilizer prices are set as a policy instrument. The government cost of fertilizer policies depends upon the difference between the world price of fertilizer and the domestic price. If the world fertilizer price is low, the subsidy may be negative. The rate of growth in fertilizer *availability* is a second policy instrument. Most governments license fertilizer plants and imports. This instrument reflects such licensing.

The available fertilizer is allocated to land of various qualities as determined by profit-maximizing rules, using the (policy-determined) fertilizer price and the (lagged market-determined) rice price. If the demand for fertilizer exceeds the quantity supplied, a shortage occurs, and the available fertilizer is allocated among land of different qualities to maximize output. If the amount available exceeds the quantity demanded, a surplus occurs, but no corresponding price adjustment occurs because of government price control. (The computer program that carries out this allocation is explained in Appendix A.)

*Irrigation Investment.* Government investment in irrigation changes the proportion of land in the various land types. Total land available for rice is assumed fixed and entirely devoted to rice production in the wet season. Irrigation investment upgrades land from rainfed to irrigated, or from low quality irrigated to higher quality irrigated land. Only a fraction of the irrigated land in the wet season has enough water to grow rice in the dry season. That fraction is increased by investments designed to upgrade the systems.

Two categories of irrigation investment are modelled: new irrigation and rehabilitation of previously irrigated land. Newly-irrigated land costs ₱8,000 per hectare while rehabilitation costs ₱2,000 per hectare.

Depreciation of irrigated land is modelled as follows: In the absence of rehabilitation investment, a certain fraction of the best quality land depreciates to second quality land; a certain fraction of the second quality land depreciates to the third quality, etc. Thus, with no irrigation investment, all land would eventually become rainfed, and even with investment, it is possible to have a decrease in irrigated area if the investment is too small. This reflects the current practice in the Philippine irrigation sector of not maintaining irrigation systems adequately.

*Population Program.* Change in the rate of population growth is modelled by specifying a target of population growth at a future target date. The greater the difference between the current and the target rate of growth, the greater is the cost of the population program.

Data for the Philippines indicate that the Population Commission plans to reduce the population growth rate from 2.5 percent/year in 1976 to 2.1 percent/year ten years later at an annual budgetary outlay of ₱350 million. Presumably, reducing the rate of population growth at any faster rate will be considerably more expensive.

In addition, other assumptions are included to reflect rural to urban migration. These are:

> The percentage of urban population to the total increases by 0.1 percentage point per year from the value of 29 percent to a value 10 years later of 30 percent.

The percentage of large farmers, small farmers and the landless to the total each declines by 0.2 percentage point per year from their initial values while the percentage of rural non-farm population to the total declines by 0.4 percentage point per year.

*Mechanization Policies.* The impact of the introduction of a number of different machines can be evaluated within the model. Each machine may have an effect on yield and on labor used. The saving in labor cost which machinery permits when it is used, and its annual cost affect the farm income of the class owning it.

It is assumed that excess demand exists for each machine so no farm level behavioral relationship governs the introduction of machines. This is perhaps the greatest limitation of the present model, but considerably more empirical research and modelling effort is needed to build an appropriate model of farmer machinery investment behavior.

Thus, the model simply computes the implications of assumed levels of machinery adoption.

Two policy instruments are available to affect machinery: subsidy on machine prices and specification of the rate of increase in availability of machinery. The first instrument has direct costs to government that are easy to compute. The costs associated with alternative assumptions about the rate of growth in availability of machinery are more difficult to specify. Including this as an instrument in the model, however, is an attempt to reflect industrial development policies or import licensing that permit rapid growth in the number of machines available to the rice sector.

## DATA AND BEHAVIORAL RELATIONSHIPS

A secondary use of the model is to help researchers clearly specify high priority areas for future research. Because it is disaggregated and descriptive, it requires a good deal of detailed information about how resources are distributed and about how the income generated in production is allocated among participants in the production process. Such information lies at the heart of understanding the issues of income distribution, and understanding of these facts is reflected in relevant portions of the following discussions. There are, however, areas where knowledge maybe lacking.

*Land Ownership.* The distribution of land by quality is central to the issues being examined. Rice is produced by small or large farmers, defined for purposes of the model as farmers with less than 3 hectares and more than 3 hectares, respectively. Census data indicate that farmers with below 3 hectares control 62 percent of all rice farms which contain 35 percent of all the area planted to rice.

Small farmers have a disproportionate share of the irrigated land. Although data are lacking for the whole country, a detailed compilation of irrigation data from the Southern Tagalog region shows that farmers with less than 3 hectares farms controlled 86 percent of the irrigated land in that region. For the entire country, it is assumed that small farmers control 50 percent of the irrigated rice area while large farmers control the other 50 percent.

Small farmers are assumed to own or have ownership rights (certificates of land tenure) for half the land they operate. Large farmers are assumed to own 65 percent of the land they operate and 25 percent of the land operated by small farmers. The rural non-farm and urban classes own the land not owned by small and large farmers.

The distribution of land of various qualities controlled by each class is shown in Table 1. As the model simulates the passage of time, the area of each quality of land changes in response to government irrigation policy and private investment decisions.

*Production Component – the Supply Side for Rice.* Rice production is carried out on large and small farms. The qualities of rice land are differentiated by season and the degree of water control on each is indicated in Table 1. Qualities 1 to 4 are wet season land, all of which can be planted to rice, and qualities 5 to 8 are dry season land, of which only the three best qualities can grow rice. The yield response to fertilizer on each type of land is specified in the model. Land can be upgraded over time through government investment. Government land investment is assumed to benefit small and large farmers by equal proportional amounts.

**Table 1**

**Initial endowments of land and its rental rates for small and large farmer classes by land quality, prototype model**

| Land quality | Small farms | | Large farms | |
|---|---|---|---|---|
| | Area ($10^3$ ha) | Rent (kg/ha/crop) | Area ($10^3$ ha) | Rent (kg/ha/crop) |
| 1 – Best irrigated, 1st season | 185 | 500 | 185 | 500 |
| 2 – Moderately irrigated, 1st season | 378 | 437 | 378 | 437 |
| 3 – Good rainfed, 1st season | 240 | 300 | 674 | 300 |
| 4 – Upland, 1st season | 198 | 300 | 304 | 300 |
| 5 – Best irrigated, 2nd season | 65 | 750 | 65 | 750 |
| 6 – Moderately irrigated, 2nd season | 130 | 500 | 130 | 500 |
| 7 – Good rainfed, 2nd season | 86 | 375 | 243 | 375 |
| 8 – Upland, 2nd season | 86 | 325 | 243 | 325 |

*Land and Fertilizer Productivity.* Land quality determines the base yield and the response to fertilizer. Because different qualities have different yield responses, each has a different capacity to productively absorb fertilizer and labor. The fertilizer response functions (Table 2), relative fertilizer and rice price, and the availability of fertilizer are used by the model to endogenously determine the rice yield and fertilizer rate on each type of land following marginal productivity principle as described in Appendix A. Thus, fertilizer is allocated optimally, producing the maximum possible rice given prices, land and fertilizer available.

Table 2

**Fertilizer response functions for each land class, prototype model**

| | Parameters in the response function | $Y = a+bF+cF^2$ | | | | | |
|---|---|---|---|---|---|---|---|
| | Wet season | | | | Dry season | | |
| Land quality | a | b | c | Land quality | a | b | c |
| 1 | 2197 | 16.2 | –0.06 | 5 | 2485 | 20.6 | –0.06 |
| 2 | 2101 | 15.4 | –0.10 | 6 | 2026 | 18.6 | –0.10 |
| 3 | 1838 | 13.3 | –0.13 | 7 | 1569 | 16.7 | –0.13 |
| 4 | 1200 | 0.0 | 0.00 | 8 | 1300 | 0.0 | 0.00 |

Source: Based on David and Barker 1978.

The response functions take the form:

$$YIELD_{ij} = a_i + b_i \, FERT_{ij} + c_i \, (FERT_{ij})^2$$

where

$a_i, b_i, c_i$, are parameters in the yield response for each quality of land, i is the subscript denoting class of land quality, j is the subscript denoting farm class;

FERT is the rate of fertilizer applied in kg/ha; and

YIELD is measured in kg/ha.

With the rates determined, yields are calculated and data on production, total fertilizer use and income of each group of farmers is provided to other components of the model. The model has been designed to allocate available fertilizer both in shortage situations and when supply is unconstrained. In some shortage situations restrictions may differentially impair the ability of certain socio-economic groups to obtain inputs like fertilizer. One type of restriction may be reflected in higher fertilizer price or higher cost credit. Another type of restriction may be an administrative ruling that gives one group priority over another group even with identical prices. To reflect this, the price of fertilizer for large farmers may differ from its prices to small farmers.

*The Effects of Mechanization.* Agricultural machinery, when introduced, has impacts on family and hired labor used per hectare and yield as indicated in Table 3. These may differ in wet and dry seasons. The yield impact is added to the yield computed from the fertilizer response functions. The effect of irrigation pumps is assumed to operate directly on yield rather than through changing the area of best quality land in order to preserve the distinction between public policy decisions on irrigation and private decisions on irrigation. Thus, when irrigation pumps are introduced, the area of best quality land is understated, but the production impact is reflected in total output.

Tractors reduce the use of family labor while increasing the use of hired labor. Irrigation pumps increase use of both types of labor since their effect is to raise yield, thereby requiring more harvest and post harvest labor. Threshers reduce the use of hired labor and give a small increase in output because of lower losses.

**Table 3**

**Coefficients for labor and yield impact of agricultural machinery, 1980**

| Item | Impact on labor (md/ha) | | | | Impact on yield (kg/ha) | |
|---|---|---|---|---|---|---|
| | Wet season | | Dry season | | | |
| | Family | Hired | Family | Hired | Wet season | Dry season |
| 2–wheel tractor[a] | –11.1 | +14.1 | –11.1 | +14.1 | 0 | 0 |
| 4–wheel tractor[a] | –11.7 | +2.6 | –11.7 | +2.6 | 0 | 0 |
| Manual transplanter[b] | 0 | –6.5 | 0 | –6.5 | 0 | 0 |
| Irrigation pump (4") [c] | +4.8 | +7.2 | +11.0 | +17.0 | +1520 | +3380 |
| Portable thresher [d] | 0 | –6.0 | 0 | –6.0 | +40 | +40 |
| Axial flow thresher [d] | 0 | –10.0 | 0 | –10.0 | +40 | +40 |

[a] Monge, V.S. 1980. "Analysis of Factors Affecting the Demand for Tractor and Power Tiller Services in Nueva Ecija, Philippines." (Unpublished M.S. thesis, University of the Philippines at Los Baños); Maranan, C., J.A. Wicks and B. Duff, 1981. "The Profitability of Two and Four-Wheel Tractor Ownership in Nueva Ecija, Philippines, 1980." (IRRI Saturday Seminar Paper, Agricultural Engineering Department).

[b] Kim, U.K. 1977. "Field Tests on Three Transplanting Systems." (IRRI Agricultural Engineering Department Paper No. 77–07.)

[c] Yield increments from Herdt, R.W., L.A. Gonzales and P. Webster. 1981. "Evaluating the Sectoral Impact of Mechanization on Employment and Rice Production in the Philippines: A Simulation Analysis," Working Paper No. 49. Consequences of Small Rice Farm Mechanization Project (IRRI Agricultural Engineering Department); Impact on labor computed as proportional to increase in yield for harvesting, handling and threshing operations only.

[d] Toquero, Z., C. Maranan, L. Ebron and B. Duff. 1977. "Assessing Quantitative and Qualitative Losses in Rice Postproduction Systems," *Agricultural Mechanization in Asia,* Vol. VIII, No. 3.

Table 4 shows the capital cost, capacity and life of each machine. As the number of machines changes, their effects are added to or subtracted from total output and total labor requirement. Their running costs are deducted from farm income. These calculations take place for each group of farmers. In this way, the effects of a mechanization policy can be followed through the model. Table 5 shows estimated machinery stocks in 1980.

The three mechanization policy instruments are:

- interest rate subsidies
- taxes and tariffs on imported machinery
- subsidy on fuel use in agriculture

These three instruments are combined into alternatives specified in terms of two variables in the model: net subsidy and growth rate of machines available (see Gonzales, Herdt and Webster 1981).

**Table 4**

**Estimated machinery capacity and cost characteristics, 1980**

| Item | Capital cost (P) | Running cost (P) | Capacity Wet | Capacity Dry | Life of Machine (yr) |
|---|---|---|---|---|---|
| 2–wheel tractor | 12,000 a/ | 223 b/ | 10 b/ | 8 b/ | 8 |
| 4–wheel tractor | 180,000 b/ | 175 b/ | 92 b/ | 88 b/ | 10 |
| Manual transplanter | 1,700 a/ | 106 d/ | 8 | 8 | 5 d/ |
| Irrigation pump | 15,600 c/ | 2250 | 10 | 10 | 10 |
| Portable thresher | 6,000 a/ | 216 e/ | 30 e/ | 20 e/ | 5 |
| Axial flow thresher | 19,000 a/ | 170 e/ | 60 e/ | | 5 |

a/ IRRI Industrial Extension program – price list.

b/ Meranan, C., J. A. Wicks and B. Duff. 1981. "The Profitability of Two and Four-Wheel Tractor Ownership in Nueva Ecija, Philippines, 1980." (IRRI Saturday Seminar, Agricultural Engineering Department).

c/ Maranan, C. 1982. "Comparative Analysis of the IRRI Six-Inch Diameter Axial Flow Pump and a Four-Inch Diameter Centrifugal Pump." (Handout for IRRI Agricultural Engineering Department Training Course); Calilung, E., et al. 1982. "Comparison of Axial Flow and Centrifugal Pumps for Low-Lift Irrigation or Drainage." (IRRI Agricultural Engineering Department.)

d/ Kim, U.K. 1977. "Field Tests on Three Transplanting Systems." IRRI Agricultural Engineering Department Paper No. 77–07; Ebron, L. 1982, "Transplanter: Economic Analysis." (Handout for IRRI Agricultural Engineering Department Training Course.)

e/ Juarez, F. and B. Duff. 1979. "The Economic and Institutional Impact of Mechanical Threshing in Iloilo and Laguna." Working Paper No. 1, Consequences of Small Rice Farm Mechanization Project (IRRI Agricultural Engineering Department).

Table 5

Estimates of machinery stock and distribution, 1980

| Item | Number in use | % Ownership | |
|---|---|---|---|
| | | Small farm | Large farm |
| 2–wheel tractor | 35,000[a] | 50 | 50 |
| 4–wheel tractor | 7,000[a] | 0 | 100 |
| Manual transplanter | 0 | 20 | 80 |
| Irrigation pump | 15,000[b] | 30 | 70 |
| Portable thresher | 10,000[c] | 70 | 30 |
| Axial flow thresher | 5,000[c] | 20 | 80 |

a/ Unpublished census data (1976) from Bureau of Agricultural Economics as cited in Monge, V.S. 1980. "Analysis of Factors Affecting the Demand for Tractor and Power Tiller Services in Nueva Ecija, Philippines," (unpublished M.S. thesis, University of the Philippines at Los Baños); additional data from Agricultural Machinery Manufacturing and Distributors Association and IRRI Industrial Extension Program.

b/ National Irrigation Administration.

c/ Juarez, F. and B. Duff. 1979. "The Economics and Institutional Impact of Mechanical Threshing in Iloilo and Laguna." Working Paper No. 1, Consequences of Small Rice Farm Mechanization Project, IRRI; IRRI Industrial Extension Program.

*Consumption – the Demand Side for Rice.* The consumption component of the model uses income and population data together with a system of demand functions to determine the demand for rice as a function of its price and per capita income. Per capita rice demand functions are specified for five population groups. They take the form:

$$DMRICE_i = C_i * PRICE_i e_i * INCOME_i n_i$$

where

$DMRICE_i$ = the quantity of rice demanded by each group

$C_i$ = the constant in the demand function

$PRICE_i$ = the market price of rice

$e_i$ = the price elasticity of demand for rice of group i

$INCOME_i$ = the per capita income of group i

$n_i$ = the income elasticity of demand for group i

*Demand Coefficients.* The model distinguishes five population groups: landless workers, small farmers, large farmers, rural non-farm and urban. The first three correspond roughly to Bouis' (1982) farmer groups, with landless falling in the first quartile, small farmers in the middle two quartiles, and large farmers in the highest income quartile. The rural non-farm groups in the model are assumed to correspond to the lowest two quartiles and the urban to the highest two quartiles in Bouis' analysis. The elasticities used in the model are given in Table 6. Note that the model does not include crosss elasticities and so demand is more inelastic with respect to its own price than Bouis' estimates.

**Table 6**

**Economic classes and their rice demand functions, prototype model**

| Class | 1980 total population, ($10^3$) | Price elasticity | Income elasticity |
|---|---|---|---|
| 1–Landless | 4835 | –0.5 | .15 |
| 2–Small farmers | 9580 | –0.3 | .05 |
| 3–Large farmers | 5784 | –0.6 | .00 |
| 4–Urban | 15674 | –0.2 | .10 |
| 5–Rural non-farm | 12204 | –0.4 | .20 |

Population growth is one of the major factors affecting the demand for food and is an important factor that many governments attempt to influence through family planning programs. The treatment of population in the model is discussed in an earlier section.

*Equilibrium Rice Price.* The equilibrium price of rice is determined within the model by the demand function and the quantity supplied. Graphically, the demand curve is downward sloping with respect to price while the quantity produced is a function of land, fertilizer and irrigation and is fixed for a given year (i.e., not responsive to price). Total supply is computed as production plus government sales plus imports minus exports and government purchases. Policy decisions control the international trade and stock levels. The equilibrium price is computed by the model using the methodology spelled out in detail in Appendix B, but essentially the model mimics the theory of market price determination, iteratively comparing alternative quantities with the quantity needed to clear the market.

*Income from Rice Production.* Each population group receives income from rice production from one or more of the sources indicated below:

| | Labor income (wages) | Rental income (land) | Farm income | Non-rice income |
|---|---|---|---|---|
| Landless | * | | | * |
| Small farmers | * | * | * | * |
| Large farmers | | * | * | * |
| Urban | | * | | * |
| Rural Non-Farm | | * | | * |

Farm income per hectare for each land quality is determined by rice yield, price of rice, quantities of inputs used and their prices (fertilizer, land, labor, machinery). The area of land and its quality operated by each class determines its farm income. Hired labor earnings which the small farmers and landless laborers receive for farm work are added to their incomes, and then per capita income from rice farm sources is calculated for each class.

Different land qualities require different quantities of labor. Machinery substitutes for labor. Each class of farmers hires a given proportion of the labor it requires for rice production. The small farmers and landless labor classes each supply half the total hired labor. The landless make up 11 percent of the population, small farmers make up 2 percent, but the landless obtain about twice as much of the hired employment as the small farmers. On the other hand, the small farmers provide labor on their own farms.

Changes in hired labor requirements lead to changes in income for landless and small farmers. If mechanization reduces hired labor, incomes of small farmers and landless laborers are reduced while those of machine owners increase because of labor cost savings. Small farmers may gain from labor costs saved by mechanization but this may be outweighed by the loss of opportunity to hire out their own labor.

## SOME PRELIMINARY ANALYSES USING THE MODEL

*The Base Run.* A common feature of simulation models is that results are expressed as changes in output variables as compared with a base run. In the present case, the base run consisted of values of policy variables which are expected in the absence of a change in present government policy. Table 7 lists the values of those primary policy variables. Table 8 shows selected results of the base run of the model: population, fertilizer

Table 7

**Policy variables used in simulation analyses**

| Policies | Values in alternative policies explored: Base run | Stimulating fertilizer use | Subsidizing machinery credit | Irrigation rehabilitation |
|---|---|---|---|---|
| Population after 10 years | 2.3 | | | |
| Irrigation: | | | | |
| Rehabilitation ('000 ha/yr) | 10 | | | 50 |
| New irrig. land ('000 ha/yr) | 50 | | | 10 |
| Fertilizer: | | | | |
| Annual rate of increase in availability | 5 | 8 | | |
| Local price (pesos/50 kg) | 125 | 80 | | |
| Mechanization: | | | | |
| Power tiller: | | | | |
| Subsidy per machine | 0 | | 300 | |
| Growth rate, % pa | 3 | | 28 | |
| 4 w tractor | | | | |
| Subsidy | 0 | | 7560 | |
| Growth rate | 1 | | 6 | |
| Manual transplanter | | | | |
| Subsidy | 0 | | 358 | |
| Growth rate | 0 | | 2 | |
| Irrig. pump | | | | |
| Subsidy | 0 | | 936 | |
| Growth rate | 3 | | 1.5 | |
| Portable thresher | | | | |
| Subsidy | 0 | | 1260 | |
| Growth rate | 3 | | 12 | |
| Axial flow thresher | | | | |
| Subsidy | 0 | | 2000 | |
| Growth rate | 0 | | 12 | |

NB values for runs 2, 3 and 4 as for base run 1 except where otherwise stated.

Table 8

Results summary : base run

| Yr | Popln | Fert | Production | Export | | per capita incomes | | | | Total lab | Hired lab | Govt cost |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (m) | ('000 t) | (mt) | (mt) | L/L | S.f. | L.f. | Urb | RN-F | (million) | (mandays) | (mil P) |
| 0 | | | | | 250 | 350 | 500 | 1000 | 500 | | | |
| 1 | 47.92 | 140.00 | 7.79 | 1.00 | 250 | 350 | 500 | 1000 | 500 | 349.3 | 231.21 | 1972.62 |
| 2 | 49.09 | 147.00 | 7.87 | 0.93 | 250 | 345 | 498 | 1000 | 500 | 349.3 | 232.07 | 1971.05 |
| 3 | 50.28 | 154.35 | 7.95 | 0.86 | 250 | 345 | 494 | 999 | 500 | 348.9 | 233.05 | 1969.39 |
| 4 | 51.48 | 162.07 | 8.03 | 0.80 | 250 | 341 | 489 | 999 | 500 | 349.2 | 234.19 | 1967.66 |
| 5 | 52.68 | 170.17 | 8.12 | 0.73 | 249 | 336 | 482 | 999 | 500 | 347.0 | 239.22 | 1965.92 |
| 6 | 53.89 | 178.68 | 8.20 | 0.67 | 249 | 330 | 472 | 999 | 500 | 345.2 | 237.21 | 1963.92 |
| 7 | 55.11 | 187.61 | 8.28 | 0.61 | 249 | 322 | 460 | 999 | 500 | 342.7 | 239.22 | 1961.91 |
| 8 | 56.34 | 196.99 | 8.36 | 0.95 | 249 | 312 | 444 | 999 | 500 | 339.3 | 241.69 | 1959.80 |
| 9 | 57.56 | 206.84 | 8.45 | 0.50 | 248 | 299 | 424 | 998 | 500 | 334.8 | 244.74 | 1957.58 |
| 10 | 58.80 | 217.19 | 8.54 | 0.45 | 248 | 283 | 397 | 998 | 500 | 329.0 | 248.52 | 1955.26 |

use, rice production, rice exports, per capita incomes, labor use and government policy costs as computed by the model over the 10 years of the base run.

Rice output increases slowly over the period due to the continuous investment in fertilizer, irrigation and machinery. But rice demand also increases, and at a faster rate, which implies that the 1 million tons of exports available in the initial year diminishes over the period. All incomes decline slightly, with the small farmers losing proportionately more than either landless laborers or large farmers. Hired labor requirement increases at the expense of family labor due to the expected increase in the number of power tillers. Total labor declines over the period. The overall picture projected by the model assuming a continuation of present government policies is one of declining rice surplus and slightly declining rural incomes. With these points considered, three runs were carried out looking at fertilizer policies, mechanization policies and irrigation policies.

*Stimulating Fertilizer Use.* The second run consisted of increasing the rate of fertilizer uptake to 8 percent by using a government subsidy of 675 pesos per ton of urea. The impact is that by year 10, fertilizer use is about 29 percent above the level projected in the base run. The result of this (Table 9, col. 1) is, however, only a small increase in rice output and is not sufficient to halt the decline in exports. These is a considerable cost to government.

This run illustrates one of the dilemmas of the present rice economy in the Philippines. Farmers are using rates of fertilizer application that are relatively high so that even substantially higher fertilizer price subsidies would result in only modest increases in fertilizer use. That extra fertilizer would result in small increases in production, because farmers are already near the top of the fertilizer response curve on each type of land. Government costs are high for this type of policy even though it leads to little increase in production.

*Subsidizing Machinery Credit.* Column 2 of Table 9 shows the effect of increasing the subsidy on credit used by farmers to purchase machinery and maintaining the current tariff rates on imported machines (alternative 2, Table 7). Total rice output is 1 percent above the base run labor use is 6 percent below the base run. Landless laborers maintain 99 percent of the income they had in the base run while small and large farmers incomes fall to 87 percent and 80 percent of the base run levels. This is because in the later years of the decade, the costs of large numbers of machines outweigh their gains to individual farmers. Labor is reduced, but family labor absorbs most of this reduction while the cost of the machinery adds more than the value of labor saved. The government cost of this program is 54 million pesos above the cost of the base run in year 10.

*Irrigation Rehabilitation.* Considerable investments are assumed in the base run — — 50,000 hectares per year of new irrigated area. But depreciation of irrigated land is taking place at 5 percent per annum and the base run reflects the approximate current practice in the Philippines of rehabilitating about 10,000 ha/yr. The third alternative illustrates the possible impact of switching investment from new irrigation to rehabilitation of existing lands.

**Table 9**

**Output variables in year 10 as % of base run variables in year 10**

| | Stimulate fertilizer | Subsidize machinery | Irrigation rehabilitation |
|---|---|---|---|
| Fertilizer use | 129 | 100 | 100 |
| Rice output | 103 | 101 | 104 |
| Rice exports | 153 | 131 | 164 |
| Per capita incomes | | | |
| L/L | 100 | 99 | 100 |
| SF | 97 | 87 | 103 |
| LF | 98 | 80 | 103 |
| UB | 100 | 100 | 100 |
| RNF | 100 | 100 | 100 |
| Total labor | 100 | 94 | 104 |
| Hired labor | 100 | 98 | 104 |
| Government cost (million pesos) in year 10 | 238 | 54 | –1584* |

*Indicates the savings for year 10, compared to the base run analysis.

Column 3 of Table 9 shows the effect of rehabilitating 50,000 hectares per year while producing only 10,000 hectares per year of newly irrigated land. This policy results in a 4 percent higher level of rice output and a 64 percent higher level of rice exports in year 10 as compared with the base run. Both small and large farmers' incomes are increased modestly as compared with the base, and total labor requirement is 4 percent higher. The government cost is reduced by 1.5 million pesos compared to the base run because of the much lower cost of rehabilitation compared to new investment.

*Lessons From the Model.* It is clear that the type of simulation model described above provides a useful approach to policy analysis. Once completed to the satisfaction of the user, it can permit rapid examination of alternative policies for their production, price, distribution, government cost and foreign exchange implications. Its skillful use does require the analyst to be competent in computer programming, know the structure of the relevant economic sector and have accurate data.

Even while recognizing the need for additional modifications to the data and relationships in the model, it is currently useful for illustrating how certain policies will have relatively little impact on production while having a massive effect on government expenditures and how alternative policies may or may not affect the incomes of different groups at different rates. For such conclusions to be valid obviously requires that a great deal of detailed knowledge of the sector be built into the model. This requirement in turn indicates to the analyst the areas of greatest and least knowledge and provides a guide to relevant research activities. Thus, a computer-oriented policy model has two tangible benefits: the quantitative results it can generate and the direction for research activities which it can provide.

## DESCRIPTION OF THE SIMULATION MODEL

The computer program is written in Microsoft BASIC as a series of chained programs for the TRS-80 Model II microcomputer with 64K of core memory. It consists of a data initialization segment followed by a main segment which controls the use of the model. The remainder of the program consists of the following series of segments, each of which is called as required from the main program:

1. Set up Initial Data
2. Main Program
3. Rice Output
4. Impact of Mechanization
5. Price Formation
6. Income Generation
7. Data Listing on Screen
8. Update Resources
9. Policy Specification
10. Computer Policy Costs
11. Write Headings
12. Data Listing on Printer

Figure 2 shows the flowchart for the main program indicating how each of the segments is called. The program may be run in a number of

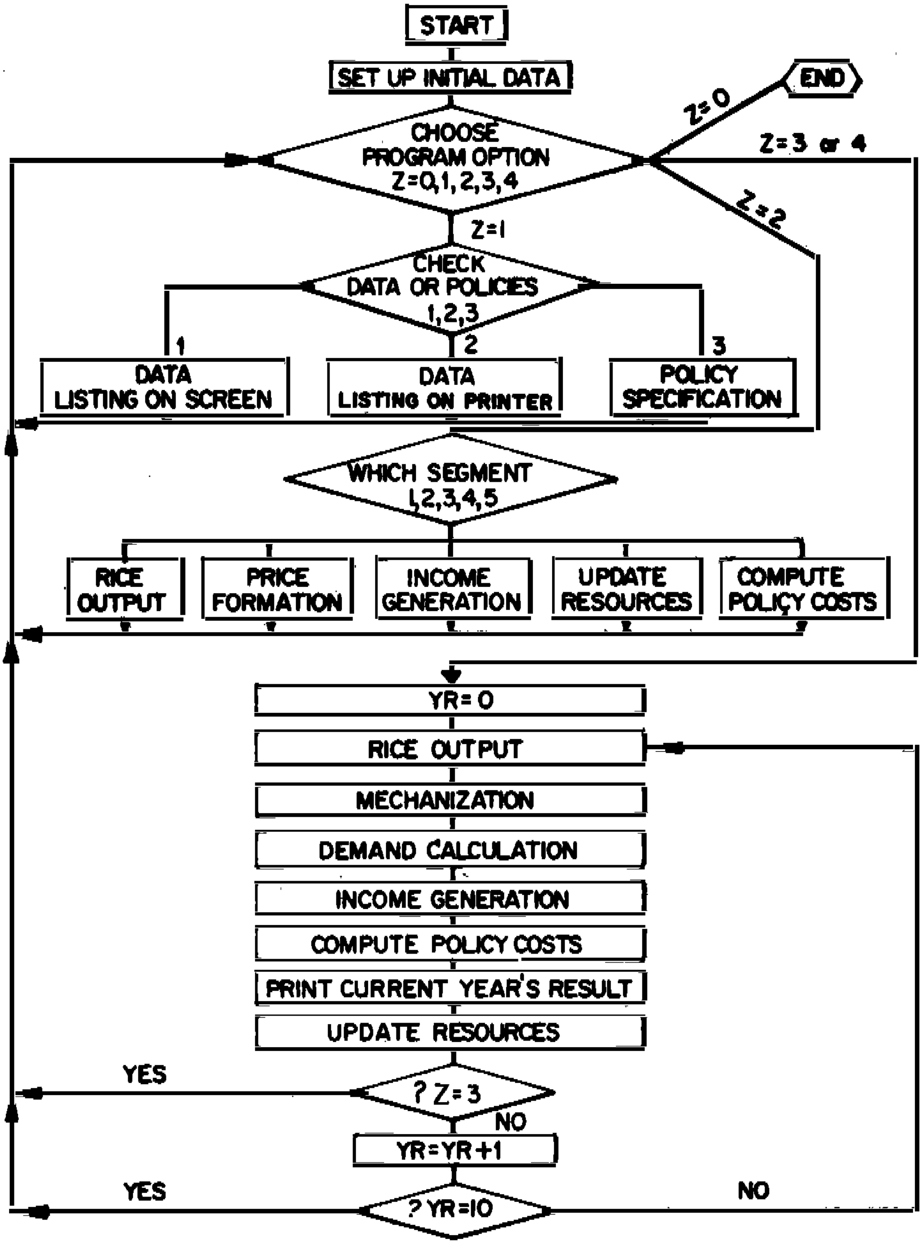


Figure 2. Flowchart for main program

alternative ways. Individual segments may be run (perhaps for testing purposes), or a single cycle may be computed, or 10 cycles (or 'years') may be computed. After each segment is run, summary information is listed but output of the complete set of current data may be generated upon return to the program option list. If computing is continued, the program uses the current data as its starting data for the next run. In this way, runs of 30 or 40 'years' may be simulated by respecifying the relevant option a number of times.

### The Existing Program Segments

#### 1. Set Up Initial Data

Function: To initialize all data variables except those contained in the 'Policy Specification' segment.

Data Requirements: values as above.

Flowchart: purely sequential.

#### 2. Main Program

Function: to control operation of the program.

Data Requirements: choice of program option; choice of segment if relevant.

Flowchart: see Figure 2.

Outputs: listing of current year's results.

#### 3. Rice Output

Function: to compute output of rice (palay) for given amount of fertilizer.

Data requirements: available fertilizer, land by quality, response functions, prices of fertilizer, and palay.

Flowchart: see Figure 3.

Outputs: yields, fertilizer dosage per hectare by land quality, total yield of palay.

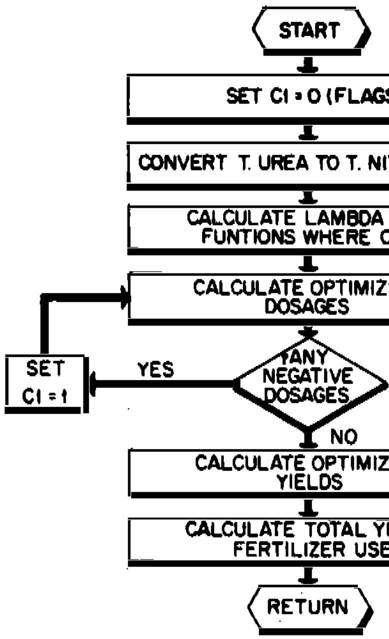


**Figure 3. Flowchart for rice output segment**

## 4. Mechanization

Function: to incorporate the effects of alternative mechanization policies into the Rice Policy model.

Data Requirements: a) Policy variables: starting numbers of machines; rate of increase of these numbers; policy costs of subsidies or taxes. b) Machinery data: effect on labor requirement by family/hired, wet/dry season; effect on yield by season, effect on intensity; capital cost, life of machine, running cost; capacity (hectare) in wet/dry season; proportion of total machines owned by small and large farms.

Flowchart: see Figure 4.

Output: effect on annual production (add to production and income) by small/large farmers; effect on family and hired labor requirement (modifies labor costs and income component); total machinery costs (subtract from income) by small/large farmers; total capital requirement.

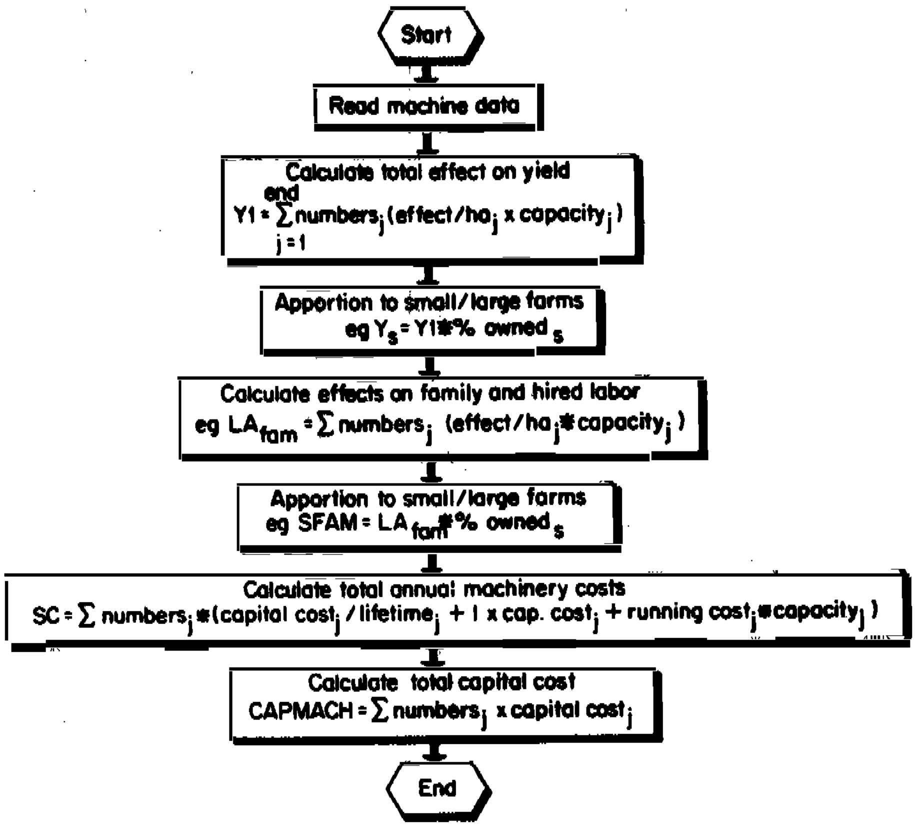


**Figure 4. Flowchart for mechanization segment**

## 5. Price Formation

Function: to calculate a market-clearing price for palay or, given a price, to calculate the imports/exports needed to satisfy current demand.

Data requirements: quantity of palay produced; incomes per capita, numbers, and demand functions by population group; palay to milled rice conversion factor.

Flowchart: see Figure 5.

Output: price of palay in pesos per kg.

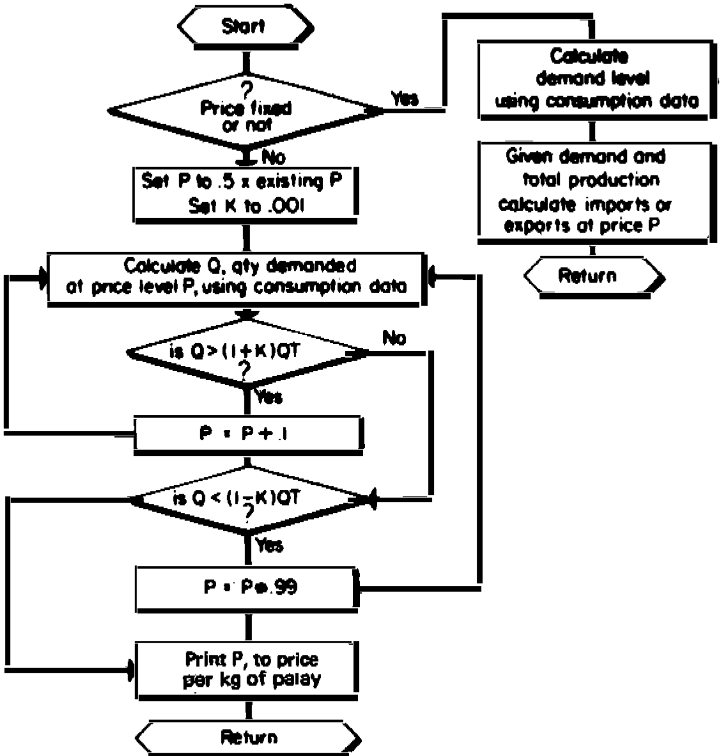


Figure 5. Flowchart for price formation segment

## 6. Income Generation

Function: to compute per-capita incomes for each of the five population groups.

Data requirements: land areas, yields/hectare, fertilizer/hectare, rents, other costs, labor requirements by season, soil-type, group, prices of palay; fertilizer, percentage of labor hired, wage rates; percentage of land owned by groups, population numbers.

Flowchart: see Figure 6.

Output: matrix of per capita incomes showing sources of income (labour, rental, rice income, other income) and total income.

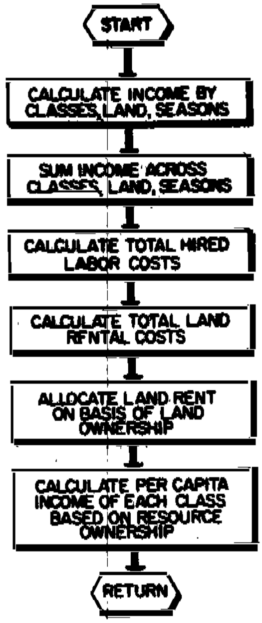


**Figure 6. Flowchart for income segment**

## 7. Data Listing on Screen

Function: to provide information on the current status of the model variables.

Flowchart: sequential only.

Output: list of variables etc. on screen.

## 8. Update Resources

Function: to allow for population growth, and changes in the areas of land and the fertilizer supply in line with policy decisions.

Data requirements: current and target rates of population increase; population group sizes; rates of transfer between groups; land areas; depreciation, rehabilitation and new irrigation rates; rate of increase of fertilizer supplies.

Flowchart: see Figure 7.

Outputs: updated population figures, land areas and fertilizer supplies.

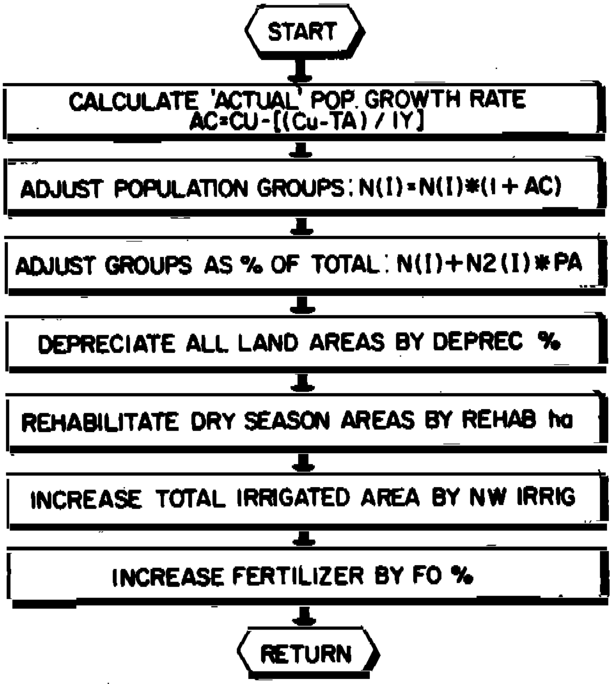


**Figure 7. Flowchart for update resources segment**

## 9. Policy Specification

Function: to allow the user to enter rates of changes of population, land areas and fertilizer supplies; to allow the price of fertilizer to be changed.

## 10. Compute Policy Costs

Function: to compute the matrix (POLCST) of policy costs.

Data requirements: policies as specified above, costs of policies as specified in Data Initialization routine.

Flowchart: see Figure 8.

Output: current annual and cumulative costs of government policies.

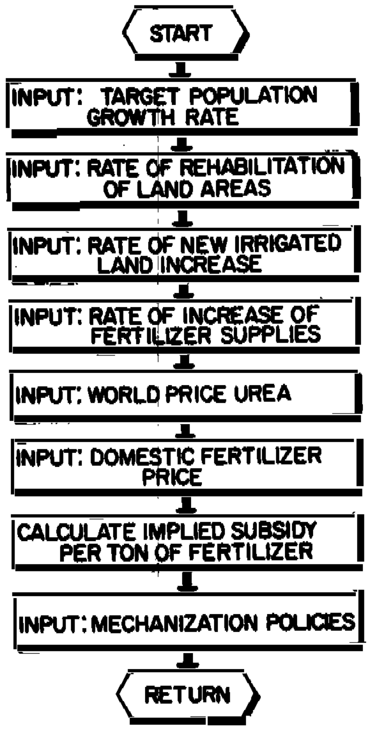


**Figure 8. Flowchart for policy specification**

## 11. Write Headings

Function: to print policies and table headings for printed output.

## 12. Data Listing on Printer

Function: as for section 6 but printed.

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## APPENDIX A

**Input format and example values for policy variables, rice sector simulation model**

### POLICY VARIABLES

**IRRI Rice Policy Model, Prototype I**

| | Base Run | Run 1 | Run 2 | Run 3 | Run 4 |
|---|---|---|---|---|---|
| Population parameters: | | | | | |
| Target Rate of growth after 10 years (% p.a.) | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 |
| Irrigation Development: | | | | | |
| Rehabilitation of areas ('000 ha/yr) | 20 | 20 | 20 | 20 | 20 |
| New irrigated land ('000 ha/yr) | 30 | 30 | 30 | 30 | 30 |
| Depreciation rate (% p.a.) | 5 | 5 | 5 | 5 | 5 |
| Fertilizer Parameters: | | | | | |
| Rate of increase in supplies (% p.a.) | 3 | 3 | 3 | 3 | 3 |
| World price of urea ($/ton) | 250 | 250 | 250 | 250 | 250 |
| Philippine price of urea (peso/50 kg) | 96.75 | 96.75 | 96.75 | 96.75 | 96.75 |
| Mechanization Policies: | | | | | |
| Power Tiller: | | | | | |
| Initial stock ('000) | 37500 | B* | B | B | B |
| Net subsidy (or tax)/machine | –600 | 0 | –600 | B | 0 |
| Expected growth rate (% p.a.) | 5 | 10 | 5 | B | 10 |
| 4–wheel Tractor: | | | | | |
| Initial stock ('000) | 2000 | B | | B | B |
| Net subsidy (or tax)/machine | 0 | B | +5000 | B | +1000 |
| Expected growth rate (% p.a.) | 1 | 1 | 2 | B | 5 |
| Manual transplanter: | | | | | |
| Initial stock ('000) | 200 | | | 10000 | 50000 |
| Net subsidy (or tax)/machine | 0 | 0 | 0 | 100 | 200 |
| Expected growth rate (% p.a.) | 0 | 0 | 0 | 10 | 20 |
| Irrigation pump: | | | | | |
| Initial stock ('000) | 10000 | B | | B | B |
| Net subsidy (or tax)/machine | 0 | +500 | B | B | +500 |
| Expected growth rate (% p.a.) | 5 | 10 | B | B | 10 |
| Portable thresher: | | | | | |
| Initial stock ('000) | 10000 | B | B | B | 10000 |
| Net subsidy (or tax)/machine | 0 | +500 | B | B | +1000 |
| Expected growth rate (% p.a.) | 10 | 15 | B | B | 20 |
| Axial flow thresher | | | | | |
| Initial stock ('000) | 5000 | | | B | B |
| Net subsidy (or tax)/machine | 0 | 0 | +1000 | B | B |
| Expected growth rate (% p.a.) | 3 | 0 | 5 | B | B |

* B = as base run.

## APPENDIX B

### Sample output from rice sector simulation model

#### I.R.R.I. Rice Policy Model

Policy summary:

—Population: present growth rate = 2.50%; growth rate in 10 years + 2.10%;
government cost = 0.11 million pesos per annum

—Fertilizer: starting supplies = 140.00 thousand ton; growth rate = 8.00% p.a.
government subsidy per tonne of urea = at local price 675.00 pesos

—Land depreciation rate = 5.00% p.a.
rehabilitation rate = 10000 has. p.a. costing 401 pesos per ha.
new irrigated land = 50000 has. p.a. costing 400000 pesos per ha.

—Mechanization policies:

Power tiller
numbers in use = 35,000, projected rate of increase = 25%, subsidy per machine = 0 pesos.

Four Wheel Tractor
numbers in use = 2,000, projected rate of increase = 1%, subsidy per machine = 0 pesos.

Manual Transplanter
numbers in use = 200, projected rate increase = 0%, subsidy per machine = 0 pesos.

Irrigation Pump 4pi
numbers in use = 15,000, projected rate of increase = 0%, subsidy per machine = 0 pesos.

Portable Thresher
numbers in use = 10,000, projected rate of increase = 3%, subsidy per machine = 0 pesos.

Axial flow thresher
numbers in use = 5,000, projected rate of increase = 3%, subsidy per machine = 0 pesos.

Results summary:

| Yr | Popln m. | Fert '000t | Yield m t | Export m t | —Per Capita incomes— L/L | S.f. | L.f. | Urb | Rn–f | Totalab million | HireLab man-days | Govt Cost m. pesos |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | – | – | – | – | 250 | 350 | 500 | 1000 | 500 | | | – |
| 1 | 47.92 | 140.00 | 7.70 | 1.00 | 250 | 360 | 521 | 1000 | 500 | 349.3 | 231.21 | 2098.62 |
| 2 | 49.09 | 151.20 | 7.89 | 0.94 | 250 | 359 | 521 | 1000 | 500 | 349.3 | 232.07 | 2106.18 |
| 3 | 50.28 | 163.30 | 8.00 | 0.90 | 250 | 357 | 520 | 999 | 500 | 348.9 | 233.05 | 2114.35 |
| 4 | 51.48 | 176.36 | 8.10 | 0.86 | 250 | 354 | 517 | 999 | 500 | 348.2 | 234.19 | 2123.16 |
| 5 | 52.68 | 190.47 | 8.21 | 0.82 | 249 | 350 | 513 | 999 | 500 | 347.0 | 235.56 | 2132.69 |
| 6 | 53.89 | 205.71 | 8.32 | 0.78 | 249 | 345 | 507 | 999 | 500 | 345.2 | 237.21 | 2142.97 |
| 7 | 55.11 | 222.16 | 8.43 | 0.75 | 249 | 338 | 497 | 999 | 500 | 342.7 | 239.22 | 2142.97 |
| 8 | 56.34 | 239.94 | 8.54 | 0.72 | 249 | 330 | 484 | 999 | 500 | 339.3 | 241.69 | 2154.08 |
| 9 | 57.56 | 259.13 | 8.66 | 0.69 | 248 | 318 | 467 | 998 | 500 | 334.8 | 244.74 | 2179.04 |
| 10 | 58.80 | 279.86 | 8.77 | 0.67 | 248 | 303 | 433 | 998 | 500 | 329.0 | 248.52 | 2193.03 |

## APPENDIX C

# Data requirements for rice sector simulation model

### DATA REQUIREMENTS*
### IRRI's Prototype Rice Policy Model

Site: ______________________________ Projection needed

Date: __________ __________ __________ Validation needed

1. Current rate of population growth (CU, 190) ______________
   after 10 years
   target rate of population growth (TA. 190) ______________

2. Coefficients of yield response functions for fertilizer ($Y=Bo +B_1F +B_2F^2$) by soil type and season (A, B, C, 240, 250)

| | Soil type | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | | | 2 | | | 3 | | | 4 | |
| Season | βo | β1 | β2 | βo | β1 | β2 | βo | β1 | β2 | βo | β1 | β2 |
| Wet | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ |
| Dry | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ |

3. Total area ('000 ha) by group, soil type and season (AREA, 260, 270)

| Soil type | Small f | | | | Large f | | | |
|---|---|---|---|---|---|---|---|---|
| Season | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| Wet | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ |
| Dry | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ |

4. Demand function: $Q = AP^EY^N$ where Q = qty, P price

A,E,N are demand function coefficients (410–450)

| | Starting income / cap | Population (millions) | E | A | N |
|---|---|---|---|---|---|
| Landless | ______ | ______ | ___ | ___ | ___ |
| Small f | ______ | ______ | ___ | ___ | ___ |
| Large f | ______ | ______ | ___ | ___ | ___ |
| Urban | ______ | ______ | ___ | ___ | ___ |
| Rural non-farm | ______ | ______ | ___ | ___ | ___ |

* Variable names and relevant statement numbers are given in brackets, e.g. (CU. 190).

Appendix C (continued)

5. World urea price (\$/t) (F1, 510) ____________
   Local price of urea (P/50 kg bag) (F2, 520) ____________
   Marketing costs of urea (P/50 kg bag) (FM, 530) ____________

6. Price of palay (P/kg) by group (P, 570)

   small farmers ____________

   large farmers ____________

7. Initial fertilizer available ('000 tons urea) ____________
   % rate of increase p.a. (F, 580) ____________

8. Labor requirements by group, soil type, and season (man-days/ha) (LAB: 660,670)

| Soil type / Season | Small farmers 1 | 2 | 3 | 4 | Large farmers 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|---|---|---|
| Wet | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ |
| Dry | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ |

9. Rents payable by group, soil type and season (kg. palay/ha.) (RENT: 700,710)

| Soil type / Season | Small farmers 1 | 2 | 3 | 4 | Large farmers 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|---|---|---|
| Wet | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ |
| Dry | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ |

10. Other costs of rice production by group, soil type, and season (kg palay/ha) (OTHER; 740,750)

| Soil type / Season | Small farmers 1 | 2 | 3 | 4 | Large farmers 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|---|---|---|
| Wet | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ |
| Dry | ___ | ___ | ___ | ___ | ___ | ___ | ___ | ___ |

Appendix C (continued)

11. Hired labor by group

| | Small farm | Large farm |
|---|---|---|
| % of labor hired (HLAB, 760) | ________ | ________ |
| Wages paid (kg. palay/day) (WGPD, 770) | ________ | ________ |

12. Proportion of class I's land owned by class J (Own; 810,820)

| | Small farmers | Large farmers | Urban | Rural | N–F |
|---|---|---|---|---|---|
| Small farmers land | ________ | ________ | ____ | ____ | ____ |
| Large farmers land | ________ | ________ | ____ | ____ | ____ |

13. Production of new irrigated land ('000 ha p.a.) (NWRG) ____________

Cost/ha of new irrigated land (P/ha) (POLCST (3,1); 840) ____________

Rehabilitation of existing areas ('000 ha p.a.) (REHAB) ____________

Cost/ha (P/ha) (PLCST (4,1); 850) ____________

Annual rate of depreciation (%) (DEPREC; 860) ____________

14. Non-rice component of per capita income

| | pesos/year |
|---|---|
| Landless | ________ |
| Small f | ________ |
| Large f | ________ |
| Urban | ________ |
| Rur N–F | ________ |

# APPENDIX D

## The Fertilizer Allocation Sub-Model

As indicated in the text, the model is designed to allocate the available fertilizer among the various land types so as to maximize profit (return above fertilizer cost). In the unconstrained case when there is more than enough fertilizer, the optimal fertilizer rate for each land type is computed by determining that quantity which equates MVP and MFC. That is, with a fertilizer response function represented as:

$$(D.\ 1) \quad Y = a + b\ F + c\ F^2$$

and a price of fertilizer equal to $P_f$, and a price of rice equal to P,

$$(D.\ 2) \quad MVP = (b + 2cF)P$$

The MFC is simply $P_f$ so the optimal quantity of F is that amount satisfying the equation

$$P_f = P\ (b + 2cF),\ \text{or}$$

$$(D.\ 3) \quad F^* = (\frac{P_f}{F} - b)\ \frac{1}{2c}$$

A number of different land qualities imply a corresponding number of different fertilizer response functions:

$$(D.\ 4) \quad \begin{aligned} Y_1 &= a_1 + b_1\ F_1 + 2c_1\ F_1^{\ 2} \\ Y_2 &= a_2 + b_2 F_2 + 2c_2\ F_2^{\ 2} \\ &\vdots \\ Y_n &= a_n + b_n\ F_n + 2c_n\ F_3^{\ 2} \end{aligned}$$

If fertilizer is unlimited, the solution of D. 3 holds for each type of land. But if the total quantity of fertilizer is less than would be required to apply the optimal amount on each hectare, the solution is a constrained optimum found as follows. Suppose the total amount of fertilizer available is F and further, suppose as in the Philipppine model that there are two classes of farmers, each owning some land of each quality: $A_{11}, A_{12} \ldots\ldots A_{1n}, A_{21}, A_{22}, \ldots A_{2n}$. The price received by each class for rice is $P_1$ and $P_2$, respectively. Represent the optimal quantity of fertilizer on each hectare of each land quality as $F_{11}, F_{12}, \ldots F_{1n}, F_{21}, F_{22}, \ldots\ldots, F_{2n}$.

The maximum amount of rice that can be produced given these limited resources is the same as the amount that would be produced by a single profit maximizing decision maker with 2n products. That is, the problem is to maximize profit, which may be written:

$$(D.\ 5)\ PR = A_{11}\ (Y_{11}P_1 - P_{f1}F_{11}) + A_{12}\ (Y_{12}P_1 - P_{f1}F_{12}) \ldots + A_{1n}\ (Y_{1n}P_1 - P_{f1}F_{1n}) + A_{21}\ (Y_{21}P_2 - P_{f2}F_{21}) + A_{22}\ (Y_{22}P_2 - P_{f2}F_{22}) \ldots + A_{2n}\ (Y_{2n}P_2 - P_{f2}F_{2n})$$

where $Y_{11} \ldots Y_{2n}$ are the optimal yields with optimal fertilizer described by the response functions for the two classes of farmers, similar to the response functions in A. 4. Profit is maximized subject to the following constraints on total fertilizer available:

$$\text{(D. 6)}\quad F = A_{11}F_{11} + A_{12}F_{12} + \ldots + A_{1n}F_{1n} + A_{21}F_{21} + \ldots + A_{2n}F_{2n}$$

**Substituting (D. 4) into (D. 5) and forming the Lagrange (L) expression gives:**

$$\text{(D. 7)}\quad \begin{aligned} PR = {} & A_{11}P_1 (a_1 + b_1F_{11} + c_1F_{11}^2) - P_{f1} F_{11} A_{11} + \ldots \\ & + A_{2n}P_2 (a_n + b_nF_{2n} + c_nF_{2n}^2) - P_{f2}F_{2n}A_{2n} \\ & + L (F - A_{11}F_{11} - A_{12}F_{12} - \ldots - A_{2n}F_{2n}) \end{aligned}$$

This system is solved for the profit maximizing levels of $F_{ij}$ by (1) first taking derivatives of (D. 7), (2) setting those equal to zero, and solving for the $F_{ij}$ in terms of L, (3) substituting the resulting values of the $F_{ij}$ into (D. 6) and solving for L, (4) then using the resulting value of L in the solutions for the $F_{ij}$ to compute numerical values of $F_{ij}$.

The computer program, written in BASIC, to allocate fertilizer following this methodology is shown as Appendix Table D.1 The following explanation of specified program lines and the flow chart (Figure 3) may help readers understand how the program works. Note that BASIC permits comments to be on the same line as program statements if followed by the symbol hypothesis ('), as for example in line 1330.

| | | |
|---|---|---|
| 1280 | : | Displays message on screen. |
| 1335 | : | L is the counter for farm classes (2)<br>I is the counter for season (2)<br>J is the counter for land types (4) |
| 1350 to 1440 | : | These statements compute the values of M1 and M2 which are components of lambda (L), which is itself computed in 1420. |
| 1440 | : | This loop computes the optimal fertilizer levels and resulting yields and output. If fertilizer is in extremely short supply, statement 1520 may result in a negative quantity applied which is, of course, impossible. In such a case, the rate for that land type is set equal to zero and some flags are set (C1 (L,I,J) = –1; FL = 1) and the solution is recomputed as controlled by statement 1590. |
| 1600 | : | Converts from tons to millions of tons. |
| 1610 | : | Computes total fertilizer used (which is useful information when there is no shortage). |

**Appendix Table D. 1**
**Rice Output Segment**

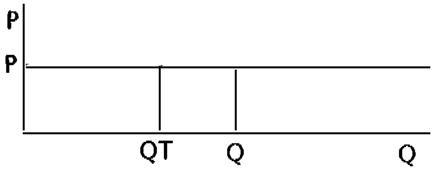
```
1240'
1250'        R I C E   O U T P U T :  BY PAUL WEBSTER AND ROBERT HERDT
1260'
1270'
1280 IF Z <> 4 THEN PRINT: **Entering 'output' . ."
1300 IF Z <> 2 THEN GOTO 1330
1310 INPUT "Available fertilizer. '000 tons";F
1320 INPUT"Price of palay, pesos/kg";P:P(2)=P
1330 F=F*1001!.46: ' convert from '000 tonnes urea to ton of nitrogen
1335 FOR L=1 TO 2:FOR I=1 to 2:FOR J=1 TO 4:cl (L.I.J)=0:NEXT J:NEXT L:'
     SET CI TO ZEROES
1340 REM Calculate lagrangian lambda
1350 MI=0: M2=0:FL=0
1360 FOR L=1 TO 2:FOR I=1 TO M: FOR J=1 TO N
1370 IF C(L.J)=0 or C1(L.I.J.)=-1 THEN GOTO 1400
1380 M1=M1+AREA (L.I.J)/(2*C(L.J)*P(I))
1390 M2=M2+(AREA(L.I.)*B(L.J)/(2*C(L.J)))-(AREA(L.I.J.)*PF(I)/(2*(C(L.J)*P(I)))
1400 NEXT J: NEXT I: NEXT L
1410 IF M1=0 THEN LA=1: GOTO 1440
1420 LA=(1/M)  *(F+M2)
1425 PRINT "F =" F
1430 REM LA is lambda
1440 IF LA   0 THEN LA=0:A$"*": PRINT" Fertilizer not limiting -- lambda set to
        "0"
1450 REM Calculate optimizing fert levels yields profits and totals
1460 TY=0: TP=0: TF=0
1470 FOR L=1 TO 2:FOR I=1 TO M: FOR J=1 TO N
1480 REM   F(L.I.J) is optimal kg fert/ha.  Y(L.I.J) is optimal yield/ha.
1490 REM   PR(L.I.J) is profit per farm
1500 F(L.I.J)=0
1510 IF C(L.J)=0 OR C1(L.I.J)= -1 THEN GOTO 1530
1520 F(L.I.J)=(PF(I)+LA)/(2*(L.J)*P(I)))-B(L.J)/(2*C(L.J)
1530 IF F(L.I.J) < 0 THEN C1(L.I.J.)= -1: FL=1' any neg appln rates. set C1 to -1  .flag
        to 1
1440 Y(L.I.J))=A(L.I.J.)+B(L.J)*F(L.I.J)+C(L.J)*F(L.I.J)) 2:   TY=TY+Y(L.I.J*AREA
        (L.I.J)
1550 PR(L.I.J)+AREA(L.I.J)*(Y(L.I.J)*P(I)-PF(I)*F(L.I.J): TP=TP+PR(L.I.J)
1560 NEXT J: NEXT I: NEXT L
1580 FOR L=1 TO 2: FOR J=1 TO 4:PRINT USING F$F(L.I.J); :NEXT J:NEXT
        L:PRINT:NEXTL
1590 IF FL=1 THEN GOTO 1340:'
1600 TY=TY/1E+06:TP=TP/1E+06
1601 PRINT" AT 1600
1602 PRINT "CALC PRODUCTION =";TY
1610 TF=0:FOR L=1 TO 2:FOR J=1 TO 4:TF=TF+F(L.I.J)*AREA(L.I.J): NEXT
        J:NEXT L
1620 F=F/(1000*.46): TF=TF/(1000*.46):' convert F and TT back to '000 ton of
        urea
1621 PRINT F:TF:POLCT(1.2)
```

```
1622 ' add extra yield. ysmall and ylarge.due to mechanization
1640 IF TF < .00001 THEN TF=0
1650 F9=F-TF: IF F9< .00001 THEN F9=)
1660 IF Z <> 4 THEN PRINT"**Quitting 'output'
1665 IF Z$="V" THEN CHAIN "PRICE"  8000.ALL
1670 RETURN
1680'*************************************************************
1690'
1700'
```

# APPENDIX E

## Equilibrium Price Determination Sub-Model

The computer program uses an iterative procedure to find the equilibrium price by (1) beginning with a trial price (Pt), (2) comparing the quantity demanded (Q) at




that price to the fixed quantity supplied (QT), (3) if Q > QT then the trial price is increased by a small amount or alternatively, if Q < QT the trial price is reduced by a small amount until Q is arbitrarily close to QT. The flow chart in Figure 5 shows the logic of the program. The BASIC code is reproduced as Appendix Table E.1.

The model can be run in one closed economy mode that allows for calculation and display of equilibrium price and a second mode allowing for the opportunity to import or export any desired quantity followed by recalculation of new equilibrium price to arrive at a satisfactory price and trade combination.

### Appendix Table E.1
### Price Formation Segment

```
8000 '      P R I C E  F O R M A T I O N BY PAUL WEBSTER AND ROBERT HERDT
8010 IF Z <> 4 THEN PRINT "**Entering 'price
8017 IF Z$ <> "V" THEN GOTO 8040
8020 TY = Ty "V" THEN TY =VL(4.VALYR)/1000
8030 PRINT " TY="'TY
8040 OR =TY * .67:                    OT is milled. TY palay from production
8050 K = .001:  REM  K is addition to quantity
8055 P=P/.67:'  P IS NOW MILLED PRICE
8060 P = .5*P:    "Starting price always lower than expected price -- -- trouble if not!
8070 IF Z <> 2 THEN GOTO 8090
8080 PRINT:    INPUT "What is the quantity produced (millions of tons of palay)"
          OT: OT = OT * Demand functions are milled rice
8090 OT = OT * 1000: 'OT is thus in '000 tons
8100 0 =0
8110 REM  This segment uses an interative procedure in which the price (P) is changed
8120 REM  until 0. the quantity demanded. approximates OT. the quantity supplied.
8130 REM  It starts by halving the old price. then moves up in steps of .1. overshoots
8140 REM  and until it approximates the desired prices. Change  it if found to be
          taking too long.
8150 '  AA (I) is population/1,000,000. so 0 is kg/1,000,000 ie '000 tons
8160 FOR I = 1 TO 5: 0 = 0 +N(I)*AA(I)*P (I))*(YY(I.5) N1(I)):NEXT I
8170 IF 0>( 1+K) * QT THEN P = P + .1: GOTO 8100
8180 IF Q<( 1-K) * QT THEN P = P * .99: GOTO 8100
8190 IF Z <> 4 THEN PRINT TAB (26);
8200 P = .67*P:P(1) = P: P(2) = PL  ' convert back to palay prices
8210 PRINT "  PALAY PRICE = "; P
8220 IF Z <> 4  THEN PRINT  " *** Quitting 'price' . . "
8222 IF Z$ = "V"  THEN CHAIN "VAL2" . 512. ALL
8230 CHAIN "MAIN"  1198. ALL
```

# A GENERAL EQUILIBRIUM ANALYSIS OF THE EFFECTS OF RICE MECHANIZATION IN THE PHILIPPINES

**C.S. Ahammed and R.W. Herdt***

## INTRODUCTION

The mechanization of a traditional agricultural system may produce substantial indirect effects on other sectors of the economy, particularly where agriculture contributes a significant share of GNP and where farm mechanization becomes relatively widespread. The indirect effects, exemplified in the concepts of 'forward' and 'backward' linkages, stem from production and consumption interactions of the agricultural sectors with the non-agricultural sectors. The production effects arise as mechanized farm production generates demand for agricultural machinery whose production in turn generates demands for engines, steel, bearings and manufacturing labor. Consumption effects originate either when there is flow of extra income from mechanization or when it leads to a redistribution of existing income. On both accounts, there are changes in the level of final demand in the economy. The production and consumption effects together may lead to changes in macro-aggregates like employment, income distribution, consumption and savings. Knowledge of these macro effects may help policymakers choose between alternative mechanization strategies in terms of their impacts on output, employment, income distribution and savings. With knowledge of the relative strength and incidence of the linkages, planners can pursue policies to achieve the desired objectives. Finally, the macro effects may give insights into possible problems that may occur when mechanization increases industrial income, thereby causing an increase in rural-urban income disparity.

Most past studies of farm mechanization effects measured the micro or direct effects of mechanization to specified farm units. Such 'micro' approaches ignore subsequent reactions in the industrial sectors and hence suffer from the standard limitations of a partial equilibrium analysis. However, without taking into account the changes in employment, income distribution and production in all sectors of the economy, both the direct effects of mechanization and the feedback effects of resulting changes in total output and income, it is not possibie to make valid, *a priori* judgments about the consequences of mechanization for the whole economy.

This paper aims to measure the magnitude and incidence of direct and indirect effects of alternative rice farm mechanization strategies. In particular, a general equilibrium macro-economic model is used with an input-output core, for measuring employment income distribution and resource utilization implications of rice-farm mechanization in the Philippines. A

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theoretical framework is presented, then, the considerations influencing the choice of methodology, are presented along with the macro-model and data set on which quantitative analysis are based. Finally, the results are presented.

## THEORETICAL FRAMEWORK

The indirect effects of farm mechanization are those that occur in sectors other than farm production. The input-output system developed by Leontief (1951, 1966) provides a framework for such a general equilibrium evaluation of the consequences of farm mechanization. Leontief's model recognizes the interdependence of industries in the economy that arises from the fact that each industry employs the outputs of other industries as its raw materials. Its output, in turn, is often used by other producers as a productive factor, sometimes by those very industries from which it obtained its ingredients. Tractors are used to produce rice, and tractors, in turn require rubber, steel and electricity. In a 'third round', rubber may require tractors and so on, ad infinitum.

The Leontief system uses an input-output table to describe the flow of goods and services within the economy over a given year. Each row shows the deliveries made by the sector associated with that row to all other sectors of the economy (including itself) and to final users. Each column shows the amount of input required and primary costs involved in the production process associated with that column. Primary costs represent 'value added' (income earned) by labor, capital and other primary factors and the sum of 'value added' is total GNP. The input-output table gives rise to a set of linear equations wherein lies the power of the input-output model. It can be used to quantify the direct and indirect transactions required to meet a given increase in direct consumption of commodities by consumers. In matrix notation, the input-output system can be expressed as $x-Ax=y$, where A is the square interindustry section of the technological coefficients (showing input requirements per unit of output), x is the column vector of total output and y is the column vector of final demand. Rearranging the linear equations yields $x = (1-A)^{-1}y$. The coefficients of the inverted matrix show direct and indirect production requirements to meet given increase in final demand.

The indirect effects arising from farm mechanization are the results of interactions between agriculture and non-agriculture in production and consumption. Production effects arise from production linkages. Mechanized rice production generates a demand for intermediate inputs and machinery. Meeting these demands generates direct and indirect demand for labor. The magnitude of the labor demand depends on the *labor intensity of production* of rice (direct), farm machinery (indirect, first round) and the production process used in obtaining the machinery that produces farm machinery (indirect, second round). There are also consumption effects arising from consumption linkages. The extra income resulting from mechanization boosts the level of final demand of those receiving the income in the economy. The magnitude and incidence of the consumption effects depend on the *consumption pattern* of household classes. Thus, if a certain household class' consumption behavior is biased in favor of labor intensive commodities, and if it is the main beneficiary of change, a mechanization strategy would tend to have greater impact on indirect employment.1/ An obviously related factor is the *income distribution pattern* of household classes. Mechanization is likely to change value added in gross output, and depending on how the additional value added is distributed to wages and profits, laborers or entrepreneurs are better off.2/ The final factor that influences the indirect effects is the *import substitution pattern* in consumption and production. Thus, on the consumption side, if laborers are net gainers from mechanical change and consume less imported products, domestic employment is greater.3/ Similarly on the production side, if a certain mechanization program embodies less imported inputs, domestic employment would be correspondingly higher. It is the net effect of all of the above mentioned factors that translate the change in degree of farm mechanization to a change in employment, income distribution and savings.

The above discussion brings out the complex system of interactions that affect the total impact of meeting final demand using alternative technologies. The model used in the study incorporates 'intensity', 'distribution', 'consumption', and 'substitution' effects in arriving at the macro-economic consequences of rice farm mechanization.

## METHODOLOGICAL CONSIDERATIONS

In order to reflect relevant alternative mechanization strategies, and to capture their direct and indirect effects, 13 rice production systems or subsectors are defined, differing by level of farm mechanization and associated water-topographical regimes. Similarly, the agricultural machinery sector is separated into 5 sub-sectors corresponding to individual machine groups and equipment. Descriptions of the rice and agricultural machinery subsectors are provided in Tables 1 and 2 respectively. The disaggregation of the rice and agricultural machinery sectors are designed to facilitate comparison of various strategies of rice farm mechanization that may occur under various water regimes.

The operation of the model proceeds on the assumption that a given increase in the exogenous demand for rice can be satisfied from the production by any of the 13 rice systems. Specifying which system will produce what amount of final demand, the model uses semi-closed input-output relations to compute domestic production and intermediate imports required to meet the demands. The factor shares of production then determine income distribution among owners of factors which in turn affects the volume and pattern of private consumption, direct imports for private

1/ Mellor, 1976, stresses the consumption effects in a somewhat broader development context.

2/ Johnson, 1954, elaborates on the effects of income redistribution on consumer's expenditure.

3/ ILO (1970) emphasizes the importance of import substitution in consumption as a determinant of employment.

consumption and savings. Finally, the model computes, for the new private consumption and income distribution, the corresponding gross output, employment, personal income, savings and imports.

The disaggregation of rice and agricultural machinery sector produces an input-output table of 46 x 46 sectors from the original 30 x 30 sectors breakdown of the 1978 Input-Output table of the Philippines.[4/]

The augmented matrix (46 x 46) had to meet two criteria: first, the individual technological coefficients corresponding to the rice and farm machinery sub-sectors had to be consistent with known differences among them. Secondly, the individual technical coefficients of sub-sectors had to aggregate into a conglomerate technological coefficient (for rice or farm machinery) equal to the sectoral coefficient that appears in the original input-output table.

**Table 1**

**Thirteen systems for rice production in the Philippines**

| System | Power | Irrigation | Thresher |
|---|---|---|---|
| 1 | Carabao | Gravity | Hand |
| 2 | Power tiller | Gravity | Hand |
| 3 | Power tiller | Gravity | Small portable |
| 4 | Tractor | Gravity | Large axial flow |
| 5 | Carabao | 4" pump | Hand |
| 6 | Power tiller | 4" pump | Hand |
| 7 | Power tiller | 4" pump | Small portable |
| 8 | Tractor | 10" pump | Large axial flow |
| 9 | Carabao | Rainfed | Hand |
| 10 | Power tiller | Rainfed | Hand |
| 11 | Power tiller | Rainfed | Small portable |
| 12 | Tractor | Rainfed | Large axial flow |
| 13 | Carabao | Upland | Hand |

4/ The 1978 I/O table (NEDA, 1978b) is an updated version of the 1974 I/O table reported in NEDA (1974).

Table 2

**Description of five agricultural machinery manufacture sectors in 1982**

| Sub-sectors | Type of machinery | Descriptions | Horse power | Cost to farmers (US$) |
|---|---|---|---|---|
| 1 | Power tiller | 2–wheel with steering clutches and attachments | 6–8 | 1,735 |
| 2 | Tractor | 4–wheel | 35 | 16,000 |
| 3 | Irrigation pump | 4" 0 axial flow propeller | 5 | 840 |
| 4 | Portable thresher | TH6–IRRI design without oscillating screen | 7 | 1,040 |
| 5 | Large axial flow thresher | TH8–IRRI design with cleaner | 12 | 2,265 |

The following illustrates the relationships between the aggregated and the separate technological coefficients.

$$(1)\quad X = \sum_{i=1}^{13} x_i ; \qquad Y = \sum_{i=1}^{13} y_i$$

Then

$$A = \frac{Y}{X} = \frac{\sum y_i}{\sum x_i} = \frac{\sum a_i x_i}{\sum x_i}$$

$$= \sum a_i \frac{x_i}{\sum x_i}$$

$$= a_1 \frac{x_1}{\sum x_i} + a_2 \frac{x_2}{\sum x_i} + \ldots + a_{13} \frac{x_{13}}{\sum x_i}$$

or, equivalently

$$(2)\quad A = a_1 w_1 + a_2 w_2 + \ldots + a_{13} w_{13}$$

X is aggregated output transaction in value terms

$x_i$ are disaggregated output transaction in value terms

$Y$ is aggregated input transaction

$y_i$ are disaggregated input transaction

$A$ is the aggregated technological coefficient

$a_i$ are the disaggregated technological coefficient

$w_i$ are the sub-sectoral weights expressing proportion of rice produced under each system.

The above derivation shows that the aggregated technological coefficient for rice appearing in the input-output table is the weighted average of the separate sub-sectoral coefficients. This relationship provides a convenient method for consistently estimating the sub-sectoral vectors from the original conglomerate vector. The same principle applies for disaggregating the agricultural machinery sector.

Two remarks need to be made here. First, since the sub-sectoral technological coefficients were obtained from farm level surveys, the right hand side of equation (2) did not automatically conform to the left hand side. In cases of such inequality, an attempt to solve the problem was done by proportional changes in the sub-sectoral technological coefficients. Second, because of the concentration on the consequences of farm-level mechanization, the differential impacts which might originate from the use of different post-threshing and milling techniques were ignored. Hence, it is assumed that the technological coefficients of inputs in the post-threshing and milling stages are the same for all paddy production systems.

In the model, five household classes were distinguished to incorporate the income distribution, consumption, saving and import substitution effects of farm mechanization. While for rice farm households, definitions rest on factors of payments criteria, namely endowments of land, labor and capital, the definitions of remaining households depend on types of activities performed. Among the five household classes, the first three belong to the rice sector.

i) hired labor households
ii) operator households
iii) landowner households
iv) non-rice farm households
v) non-farm households.

The hired labor households derive their income from offering labor services to rice farmers. Landowner households include farmers as well as landlords. Their income consists of the returns from land and capital. The farm operator households are renters of land and they obtain earnings from both capital and labor. Incomes of non-rice farm and non-farm households are assumed to depend on gross output produced in these sectors.

The inclusion of these five sets of households provides a mechanism within the model to reflect variation in consumption, saving and import behavior by the population classes directly affected by rice farm mechanization. The separation of farm and non-farm households allows measurement of changes in rural-urban income distribution caused by alternative mechanization programs.

The model calculates total savings available under different rice production systems. Differences in savings behavior among household classes combined with differential changes in household incomes account for changes in the saving rate.

Imports are separated into two kinds: imports for intermediate uses and imports for final consumption. Intermediate imports depend on production linkages while imports for final uses are determined by consumption linkages.

Private consumption of each commodity is divided among the household classes in accordance with their consumption behaviors. The model distinguishes consumption of domestic from imported items, but due to lack of data, consumption imports are not separated into individual items but allocated as a whole to each of the household classes.

## DESCRIPTION OF THE MODEL

Consider a set of material balances among n production sectors and h household classes.

$$(3) \quad X_i = \sum_{j=1}^{n} a_{ij} X_j + \sum_{k=1}^{h} c_{ik} Y_k + F_i$$

where

- $X_i$ denotes the gross output of sector i
- $a_{ij}$ the input value of commodity i needed to produce a unit value of commodity j
- $c_{ik}$ is the expenditure coefficient of household class k on commodity i
- $Y_k$ is the income of household class K
- $F_i$ is other final uses of commodity i including such items as government consumption expenditure, gross domestic capital formation, exports and imports.

Since consumption purchases are made dependent on the level of income of the particular group, $F_i$ represents an exogenous variable of the model whose value can be changed at will to conduct policy exercises.

Total import is disaggregated by two groups: import for intermediate use and import for consumption.

$$(4) \quad M = \sum_{j=1}^{n} a_{mj} X_j + \sum_{k=1}^{h} c_{mk} Y_k$$

where

$M$ is the value of total imports

$a_{mj}$ is the value of intermediate imports needed to produce a unit value of commodity j

$c_{mk}$ is the expenditure coefficient of household class k on imports.

Total savings are obtained by summing savings of various income groups.

$$(5) \quad S = \sum_{k=1}^{h} c_{sk} Y_k$$

where

$S$ is total savings

$c_{sk}$ is the savings propensity of income group k.

Gross value added in each of the rice systems is separated into payments to hired labor, payments to operators and payments to landlord. These payments determine income for the first, second and third group of the household classes. Non-rice farm income and non-farm income are assumed to be fixed portions of total output in these sectors. Thus, income for the population class k can be expressed by the following equation.

$$(6) \quad Y_k = \sum_{j=1}^{n} a_{kj} X_j$$

where

$a_{kj}$ is income component generated for household class k per unit of commodity j produced.

Finally, total labor requirements in the economy are obtained by summing labor requirements of all the n industries:

$$(7) \quad L = \sum_{j=1}^{n} a_{1j} X_j$$

where $a_{1j}$ is labor coefficient.

The following relationships hold in the model:

$$\sum_{i=1}^{n} c_{ik} + c_{mk} + c_{sk} = 1$$

The relationships (3—7) can be presented as follows:

$$
\begin{array}{llllll}
(3') & X(I\text{-}A) & - C_c Y_k & & = F \\
(4') & - XA_m & - C_m Y_k & + M & = 0 \\
(5') & & - C_s Y_k & + S & = 0 \\
(6') & - XA_k & & + Y_k & = 0 \\
(7') & - XA_1 & & + L & = 0
\end{array}
$$

where

- $X$ is vector of outputs with dimension 46 x 1
- $A$ is the square matrix of size 46 x 46 of input coefficients
- $C_c$ is a rectangular matrix of size 46 x 5 of domestic consumption coefficients $c_{ik}$ of 5 household classes
- $Y_k$ is a vector of household class incomes with dimension 5 x 1
- $F$ is a vector of other final uses with dimension 46 x 1
- $A_m$ is a row vector of import coefficients $a_{mj}$ of size 1 x 46
- $C_m$ is a row vector of private consumption for imported goods $a_{mk}$ of size 1 x 5
- $M$ is total imports
- $S$ is total savings
- $C_s$ is a row vector of private savings $c_{sk}$ of size 1 x 5
- $A_k$ is a rectangular matrix of size 5 x 46 of income coefficients
- $A_1$ is a row vector of size 1 x 46 of labor coefficients
- $L$ is total labor requirements

Expressed in matrix notation as:

$$
\left[\begin{array}{c|c|c|c}
I\text{-}A & 0 & -C_c & 0 \\
\hline
-A_m & & -C_m & \\
 & I & & 0 \\
0 & & -C_s & \\
\hline
-A_k & 0 & I & 0 \\
\hline
-A_1 & 0 & 0 & I
\end{array}\right]
\left[\begin{array}{c}
X \\
\hline
M \\
S \\
\hline
Y_k \\
\hline
L
\end{array}\right]
=
\left[\begin{array}{c}
F \\
\hline
0 \\
\hline
0 \\
\hline
0
\end{array}\right]
$$

or $Q \cdot R = S$

where $Q$ is a square matrix of size 54 x 54 pertaining to structural coefficients

R is a column vector of the endogenous variables of size 54
S is a column vector of the exogenous variables of size 54

The solution is therefore

$$R = Q^{-1}S$$

The elements on the main diagonal of matrix are positive. Moreover, remaining non-zero elements are negative and, with the exception of the import coefficients, are smaller than one. It can therefore be expected that matrix Q must have an inverse.

To isolate the effect of farm mechanization, the model is simulated by considering the effect of a 1 percent increase in final demand for rice satisfied from each of the production systems in turn, that is, m subsets of final demand vectors are considered. Each vector contains one positive element for the system by which a given quantity of rice is produced, while the rest of the elements are taken to be zero. In each case, the vector of endogenous variables generates:

1) direct and indirect employment
2) income distribution
3) savings
4) import
5) direct and indirect requirements of inputs.

The model shows what the equilibrium state of the economy looks like under alternative states of rice farm mechanization. The total impact on the economy is calculated not only as the sum of (a) labor intensity, (b) consumption, (c) income distribution, and (d) import substitution effects, but also as the feedback effects of resulting changes in total output. The exercise is a static comparative simulation of additional rice production from 13 alternative systems of rice production corresponding to different assumptions about water control, topography and degree of mechanization. A system of exclusively linear homogenous equations which allows for solutions by simple matrix inversion operation is used.

The most important limitations of the model are the assumptions of Leontief's linear homogeneous production function, constant returns to scale and no economies of scale, free labor force resources and no capacity limitations, and no balance-of-payments limitations.

## DESCRIPTION OF DATA

The data required by the model were obtained from various sources and are described below. Some of the data were not available and were estimated.

**Rice production systems**

The model distinguishes among the 13 systems of rice production identified in Table 1. In three of the four kinds of water-topographical regimes (gravity, pump, rainfed) land preparation and threshing are carried out using various degrees of mechanization. The upland system is non-mechanized. The following cropping intensity indices are assumed: gravity 122 percent, pump 200 percent, rainfed 105 percent, upland 85 percent.

Three alternative techniques of land preparation are available: carabao (water buffalo), power tiller, and tractor. It is recognized that some farmers may combine two of the above techniques for land preparation in their farms. Three threshing techniques are included: manual, portable and large axial flow thresher. In Table 1, the rice production systems are arranged in ascending order of mechanization within a given water regime. The first involves zero level of mechanization, the fourth a fully mechanized system while the second and third represent intermediate technologies.

The quantity data on gravity systems were obtained from Herdt and Lacsina (1976). The price data from 1978 were obtained from the Bureau of Agricultural Economics (BAECON). The source of farm data was a survey of Central Luzon and Laguna farmers carried out by the Economics Department of the International Rice Research Institute (IRRI) in 1975.

Pump irrigation systems are gaining popularity throughout the Philippines and are widespread in Laguna. Data for the Laguna irrigation system were obtained from Herdt and Lacsina (1976) based on a survey of Laguna farms in 1973-74.

Rainfed farming is widespread in Bicol and Iloilo regions. Our data on rainfed areas were obtained from a 1977 survey of Iloilo reported by Herdt and Gonzales (1980).

Upland systems comprise 11 percent of total rice area and is most prevalent in Cagayan Valley, Southern Tagalog, Bicol, Western Visayas; Eastern Visayas, Southern and Northern Mindanao. The data on upland rice production were based on a 1973 survey by Dozina and Herdt (1974).

A budget was developed for each of the rice production systems, showing the breakdown of costs and the earnings accruing to hired labor, operator, and landowner. The budgets appear in Appendix A. Total value of output was allocated to intermediate inputs, labor earnings, return to land, taxes and operator's residual. Within the intermediate inputs, machinery was separated from the other sectors (seed, carabao, fertilizer and other chemicals, fuel and lubricants).

Cost of agricultural machinery use was separated into (i) depreciation, (ii) returns to capital, (iii) fuel and lubricants, (iv) repair and (v) labor costs.[5/] Repair costs were assumed to consist half of labor cost with the other half distributed to depreciation and returns to capital in the same proportion as for the original machine. Capital consumption allowance

[5/] The assistance of the IRRI Agricultural Engineering Department in this is appreciated.

include returns to capital for both the machinery and the spare parts plus interest charges.

Once the returns to land, labor and capital had been calculated, they were apportioned to household classes in the following manner. Landowner's income equals rent on land, 50 percent of capital consumption and family labor allowances. Income of hired labor households is the value added by hired labor. The income of operator households correspond to the residual 50 percent of capital consumption and family labor allowances. Indirect taxes are subtracted from each cost component and aggregated to show indirect taxes collected from rice production. Tax and tariff rates on agricultural inputs and machinery were obtained from the Tariff and Customs Code of the Philippines.

The model requires the current proportion of paddy produced under each of the rice production systems. Though data is available on the amount of paddy grown under each water-topographical regime, its breakdown into different levels of mechanization is not available. These figures were arrived at in two stages. In the first step, the proportion of paddy area under mechanization and proportion of paddy mechanically threshed, are estimated and in the second step, the two proportions to various water and topographical regimes are allocated in a consistent manner. The proportions of rice produced under various systems are indicated in Appendix A. For estimating the proportion of rice area by type of mechanization, the BAECON (1976) survey of agricultural machinery was used. The survey found that 25,939 power tillers and 12,957 tractors were in use in the agricultural sector. Based on sales figure published by the Agricultural Machinery Manufacturers and Distributors Association (AMMDA), 92 percent of power tillers and 47 percent of tractors were used in rice production. Studies conducted by the IRRI Engineering Department (Orcino 1972; Orcino and Duff 1973) found that on average, power tillers and tractors are used for 440 and 1400 hours respectively in a year. These studies also found that power tillers and tractors require 25 hours and 5 respectively to plough one hectare. Since the BAECON survey counted agricultural machinery irrespective of their productive life spans, an assumption of 50 percent utilization levels was made for the aggregate stock of agricultural machinery used in paddy production. These figures together indicate that 1.06 million hectares or 28 percent of total national rice area is under mechanization. This area is allocated among various water regimes in the following manner. Fifty percent of the area in pump and gravity irrigation systems use power tillers or tractors, 15 percent of rainfed system use them while upland systems use only carabao.

For estimating the proportion of paddy which is mechanically threshed, the unpublished data of the National Grains Authority (NGA) which found 11,500 threshers in 1979 was used. Field interviews by the IRRI Engineering Department showed that the IRRI designed axial flow thresher (old model) was used for 500 hours per year and the portable (old model) thresher was used 300 hours in a year. The interviews with farmers also showed that 1.5 hours of machine time was required to thresh one ton of paddy by large axial flow thresher and 2.5 hours was required by the small thresher. With the assumption of 50 percent utilization, it appears that 1.38 million tons or nearly 20 percent of the total paddy was mechanically threshed. This total was allocated to different water regimes in the following manner: 40 percent of pump and gravity irrigated rice was mechanically threshed, 7 percent of rainfed rice and 0 percent of upland rice.

Paddy yield is assumed to depend on water availability and topography for a given variety of seed. Mechanization does not affect yield.

### Agricultural machinery subsectors

The model uses a 5 subsectoral breakdown of the agricultural machinery sector into power tiller, tractor, irrigation pump, portable and large axial flow threshers (Table 2). For each of the machines, a budget was developed showing intermediate and primary costs involved in their construction (Appendix B). The cost data were obtained from the industrial extension unit of the IRRI Engineering Department.

Three sectors supplied materials to agricultural machinery — basic metal and purchased material, paints and chemicals and rubber products. Small machines like power tillers, threshers, and irrigation pumps are domestically manufactured with imported engines, while four-wheel tractors are imported on either partly knockdown (PKD) or a completely knockdown (CKD) basis.

Labor costs refer to total compensation of employees, while the cost categorized as other is residual item showing profit, dealer's margin, returns to capital and interest charges.

Information on tax and tariff rates were obtained from the Tariff and Customs Code of the Philippines.

The same procedure utilized in the rice production sector was used for consistently segregating the conglomerate technologoical coefficient of the agricultural machinery sector into separate subsectors, namely, power tillers, tractors, irrigation pumps, portable and axial flow threshers.

The weights or the proportion of capital asset under each of the machinery sector is estimated from existing number of machineries in each of the subsectors.

### Input-Output Table

The 63 sector classification of 1978 Input-Output table of the Philippines constructed by the National Economic and Development Authority (NEDA) is the basic source of information on intersectoral transactions. It provides sectoral information on value added by primary factors, indirect taxes less subsidies, private and government consumption expenditure, domestic capital formation, exports and imports.

For the purposes of the model, the original input-output table of 63 sectors was aggregated into one with 30 sectors (Appendix C). The 30 producing sectors that are distinguished for the purposes of the model, include a combined rice milling and paddy production (sector 1), other agriculture (2 and 3), mining (4), food processing (5 and 6), consumption and intermediate goods (7-15), capital goods (16-20), supply goods (21-25) and services of diverse nature which are sufficiently explained by their titles (26-30).

**Consumption Expenditure**

The data on consumption expenditure patterns of households were obtained from the 1975 Family Income and Expenditure Survey of the National Census and Statistics Office (NCSO). Five household classes are assumed to correspond to five income classes; landowners to income range ₱8,000 – ₱10,000 which is income of the highest 10 percent of rural households; operators to income range ₱3,000 – ₱4,000 which is the income of the median group of rural households; hired labor to income range of ₱1,000 – ₱1,500 which is income of the lowest 10 percent of rural households; non-rice farm households to income range ₱4,000 – ₱5,000 which is the income of average rural households and non-farm households to income range ₱6,000 – ₱8,000 which corresponds to average income of urban households. The model requires distinguishing consumption expenditures on each item by household classes. For this purpose, consumption items were first aggregated from the original 45 sectors of the 1975 Family Income and Expenditure survey into a 30 sector breakdown to correspond to the 1978 Input-Output Table. For durable agricultural machines like power tiller, tractor, pumps and threshers, consumption purchases signify investment spending. The investment behavior of rice-farm household classes is assumed to be identical to their savings behavior.

**Imports**

Data on imports are available from the 1978 Foreign Trade Statistics of the Philippines published by NCSO. Information on imports for intermediate uses by sectors were obtained from the 1978 input-output accounts of the Philippines. The model requires data on import propensities of consumption for different household classes. Since such information was not available, estimation was based on other sources like the 1975 Family Income and Expenditure Survey. The estimation procedure involved three steps. In step 1, the aggregate import propensity is calculated from information on total import for consumption and national income. In step 2, the shares of major consumption items which involve a high percentage of imports like clothing and footwear, fuel and light, rubber and chemical products, medical care and recreation in the households income are estimated. In step 3, the aggregate import propensity among various household classes are consistently allocated. The above procedure yields only approximate estimates of the import propensities by income groups but are nevertheless useful.

**Savings and Taxes**

Savings and taxes include personal plus corporate savings and direct plus indirect taxes. Data on aggregate savings and taxes are obtained from the publication by NEDA entitled National Income Accounts 1978. The aggregate savings and tax figures are disaggregated into separate household classes of the model. The savings rate in the rice production sector is assumed to equal that of rural households savings rate calculated to be 9.1 percent (R. Bull 1977). The 1975 Family Income and Expenditure survey is utilized for disaggregating rural savings and tax rates to different household classes.

### Labor Force

Data on labor force are taken from the survey of households bulletin (1978) of the National Census and Statistics Office. The data include both unemployed and employed labor force. Payroll per employed person is found by dividing total compensation of employees by labor force.

## SIMULATION OF THE MACRO-ECONOMIC MODEL AND CALCULATION OF RESULTS

In order to demonstrate the potential of the model, the impact of a one percent increase in consumer spending for rice is simulated so that in each simulation, the additional consumer demand is fully met from a specific system of rice production. The simulation involved post-multiplying the inverted matrix with the final demand vector (F) reflecting the one percent increase in consumer spending for rice. In each case, the vector of endogenous variables generates increases in direct and indirect employment, rise in income by household classes, and increase in savings and imports. For calculating the additional requirement of inputs, it became more realistic to consider a one percent increase in rice production rather than one percent increase in consumer spending but again supply is assumed to be met from the specific rice production sector. One percent of total consumer spending for rice was found to equal P99.3 million with purchase capacity of 45.2 thousand tons of milled rice or 76.5 thousand tons of rough rice (palay). One percent of rice production was almost the same – 45.5 thousand tons of milled rice or 76.7 thousand tons of rough rice (palay) with gross value of P190.1 million. The results are summarized below in terms of employment, resource requirements, income distribution within the rice economy and among household classes, and income, consumption, savings and imports.

### Employment

Employment refers to the total labor force employed and is calculated by dividing compensation of employees by weighted average payroll per employee. The direct effects of employment are a reflection of the labor/output ratios appearing in budget studies, the indirect effects a reflection of labor use in industries that are related to rice production by 'backward' and 'forward' linkages, taking into account both the production and consumption effects.

The results are shown in Table 3. Total employment in the economy as it operated in 1978 is estimated at 16.968 million. The data in column (1) show total employment if a 1 percent increase in rice production is met from each specified sector in turn. Column 2 shows the increased employment.

The results indicate that pump irrigation systems provide the greatest potential for employment increases – 37 to 55 thousand worker increase – followed by gravity, rainfed and upland systems. Within a given water regime, employment falls with higher degrees of mechanization, but within a mechanization level employment rises with higher degrees of irrigation. If one compares the impact using mechanized techniques of rice production under gravity or pump systems (36/37 thousand increase) with traditional technique under rainfed (31 thousand) and upland (18 thousand) it is evident that even the least labor intensive irrigation system absorbs more labor than the most labor intensive rainfed system. Thus low productivity due to lack of water control and inadequate inputs rather than mechanization per se is responsible for low employment. As expected, the direct or on-farm employment usually declines with greater intensity of mechanization (col. 3) and accounts for 50-80 percent of total (direct and indirect) decline of employment in a given water regime. On the other hand, indirect employment (col. 4) is little affected by increase in the intensity of mechanization, except in the rainfed case and in the most highly mechanized system. The failure of indirect employment to increase under rainfed cultivation and in fully mechanized systems is probably due to redistribution of income to households with low consumption and high import propensities. The ratio of indirect/direct employment effect rise with increases in the intensity of mechanization under all regimes (col. 5) pointing to the fact that linkages assume a greater role under mechanization. Finally, the results show, not surprisingly, that micro-studies using on-farm employment data overestimate the net displacement of labor in all except the fully mechanized systems in irrigated regimes. Furthermore, it is observed that the greater the intensity of mechanization, the larger is the overestimation. On the other hand, under rainfed cultivation and in the fully mechanized systems on-farm employment data underestimates the true displacement of labor and here, the greater the intensity of mechanization, the smaller is the underestimation.

## Resource Requirements

The resource requirements (direct and indirect) of sustaining the given increase in rice production from each source are reflected in "quasi-elasticities" derived from the model and interpreted like conventional elasticities. Because the quasi-elasticities were obtained from the solution of the general equilibrium model they indicate input requirements not only in the rice sector but also in the non-rice sectors that are related in a direct

Table 3

**Employment implications of a one percent increase in consumer spending for rice when demand is met from specified production sector**

| Sector number | Rice Production Sectors: Power | Irrigation | Thresher | | Total employment (thousands) (1) | Absulute increase (thousands) (2) | Direct increase (thousands) (3) | Indirect increase (thousands) (4) | Ratio of indirect/direct employment effect (5) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Actual Economy, 1978 | 16,968 | | | | |
| 1 | Carabao | Gravity | Hand | | 17;010 | 42 | 14.5 | 27.5 | 1.89 |
| 2 | Power tiller | Gravity | Hand | | 17,011 | 43 | 15.9 | 27.1 | 1.70 |
| 3 | Power tiller | Gravity | Small portable | | 17,008 | 40 | 12.4 | 27.6 | 2.23 |
| 4 | Tractor | Gravity | Large axial flow | | 17,004 | 36 | 11.2 | 24.8 | 2.21 |
| 5 | Carabao | 4" pump | Hand | | 17,023 | 55 | 23.7 | 31.3 | 1.32 |
| 6 | Power tiller | 4" pump | Hand | | 17,021 | 53 | 21.7 | 31.3 | 1.44 |
| 7 | Power tiller | 4" pump | Small portable | | 17,017 | 49 | 17.4 | 31.6 | 1.82 |
| 8 | Tractor | 10" pump | Large axial flow | | 17,005 | 37 | 9.0 | 28.0 | 3.11 |
| 9 | Carabao | Rainfed | Hand | | 16,999 | 31 | 11.0 | 20.0 | 1.81 |
| 10 | Power tiller | Rainfed | Hand | | 16,996 | 28 | 9.7 | 18.3 | 1.89 |
| 11 | Power tiller | Rainfed | Small portable | | 16,995 | 27 | 7.3 | 19.7 | 2.70 |
| 12 | Tractor | Rainfed | Large axial flow | | 16,991 | 23 | 5.3 | 17.7 | 3.34 |
| 13 | Carabao | Upland | Hand | | 16,986 | 18 | 5.1 | 12.9 | 2.53 |

or indirect way. The quantitative values of the quasi-elasticities can be used by policymakers wanting a general equilibrium solution of the input requirements by all sectors of the economy.

The irrigated systems have relatively higher requirements of all the intermediate inputs as reflected in their higher quasi-elasticities. On the other hand, a one percent increase in rice production would require 61,000 hectares of upland, 38,000 hectares of rainfed, 25,000 hectares of gravity irrigated or 19,000 hectares of pump irrigated land.

The results in Table 4 show that mechanization leads to an increase in efficiency of individual input utilization as indicated by the decline in quasi-elasticities with increasing levels of mechanization. The greatest increase in efficiency for fertilizers and chemicals are derived with mechanization in rainfed conditions and for petroleum products with mechanization in pump irrigation systems.

Petroleum products and carabao services enter households' consumption functions either in a direct or indirect way. Intermediate results (not shown) indicate that 60 percent of the increase in petroleum and 35 percent of the increase in carabao services are due to increases in consumption resulting from increases in income.

The model contains the assumption that the purchase of agricultural machinery like power tillers, tractors, irrigation pumps and threshers are dependent on the savings behavior of household classes. Given the existing production, consumption and income distribution parameters, most investments in agricultural machinery are likely to occur in pump irrigated systems, followed by gravity and rainfed systems. Upland systems, because of their extremely low productivity, represent the least desired area of agricultural investment.

## Income distribution within the rice economy

The results on income distribution within the rice economy obtained from the model are presented in Table 5. In the table, income inequality is measured by the ratio of landowner/hired labor and operator's gain in income.

The results indicate that using pump irrigation systems to produce the increased rice leads to the greatest increase in income for the rice economy closely followed by gravity and distantly followed by rainfed and upland systems. It is further observed that the increments to income in the rice economy fall off with increasing levels of mechanization. This probably occurs as the positive production effects are gradually offset by negative consumption effects resulting from the lower propensity to consume of the main beneficiary of mechanical change, i.e. landowner. The model does not reflect how landowners might utilize this additional savings and it is likely that incorporation of their investment behavior would present a different picture about long term income generation capacities of the mechanized systems. Even with the present model, the increments to income from a mechanized system in a given water regime may be higher than from a non-

Table 4

Quasi-elasticities showing the direct and indirect resource requirements of a one percent increase in rice production from a specified rice production sector

| Sector number | Rice Production Sectors: Power | Irri-gation | Thresher | | Ferti-lizer | Chemical products | Petro-leum products | Carabao and other agri-cultural service | Power tiller | Tractor | Irri-gation pump | Small portable thresher | Large axial flow thresher |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Actual Economy, 1978 Total (mil ₱) | 1395.4 | 9589.6 | 11240.1 | 10606.8 | 134.1 | 154.9 | 22.0 | 18.2 | 33.8 |
| 1 | Carabao | Gravity | Hand | | 0.564 | 0.246 | 0.164 | 0.231 | 0.221 | 0.292 | 0.265 | 0.226 | 0.206 |
| 2 | Power tiller | Gravity | Hand | | 0.561 | 0.248 | 0.168 | 0.215 | 0.400 | 0.293 | 0.266 | 0.226 | 0.206 |
| 3 | Power tiller | Gravity | Small Portable | | 0.557 | 0.245 | 0.164 | 0.209 | 0.410 | 0.302 | 0.275 | 0.853 | 0.215 |
| 4 | Tractor | Gravity | Large Axial flow | | 0.549 | 0.228 | 0.152 | 0.206 | 0.207 | 0.715 | 0.247 | 0.212 | 0.678 |
| 5 | Carabao | 4" Pump | Hand | | 0.487 | 0.286 | 0.199 | 0.270 | 0.251 | 0.335 | 2.170 | 0.257 | 0.234 |
| 6 | Power tiller | 4" Pump | Hand | | 0.478 | 0.284 | 0.198 | 0.250 | 0.418 | 0.337 | 2.160 | 0.259 | 0.236 |
| 7 | Power tiller | 4" Pump | Small Portable | | 0.473 | 0.278 | 0.193 | 0.241 | 0.436 | 0.343 | 2.190 | 1.056 | 0.245 |
| 8 | Tractor | 10" Pump | Large Axial flow | | 0.499 | 0.278 | 0.172 | 0.205 | 0.229 | 0.532 | 3.770 | 0.234 | 0.713 |
| 9 | Carabao | Rainfed | Hand | | 0.384 | 0.176 | 0.122 | 0.186 | 0.139 | 0.192 | 0.172 | 0.143 | 0.131 |
| 10 | Power tiller | Rainfed | Hand | | 0.371 | 0.169 | 0.118 | 0.148 | 0.362 | 0.198 | 0.179 | 0.152 | 0.138 |
| 11 | Power tiller | Rainfed | Small Portable | | 0.376 | 0.177 | 0.123 | 0.154 | 0.375 | 0.218 | 0.199 | 0.582 | 0.155 |
| 12 | Tractor | Rainfed | Large Axial flow | | 0.365 | 0.161 | 0.111 | 0.151 | 0.145 | 0.705 | 0.174 | 0.149 | 0.520 |
| 13 | Carabao | Upland | Hand | | 0.153 | 0.114 | 0.084 | 0.133 | 0.094 | 0.129 | 0.116 | 0.097 | 0.088 |

Table 5

Income redistribution implications for rice farm households of a one percent increase in consumer spending for rice when demand is met from specified rice production sector

| Sector number | Rice Production Sectors: Power | Irrigation | Thresher | Hired labor: Absolute increase (million peso) | Hired labor: Incremental share | Operator: Absolute increase (million peso) | Operator: Incremental share | Landowner: Absolute increase (million peso) | Landowner: Incremental share | Ratio of Landowner/hired labor and operator incremental income | Total incremental income of rice farm |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Actual Economy, 1978 Income (mil ₱) | 2594 | – | 3469 | – | 2503 | – | – | 8566 |
| 1 | Carabao | Gravity | Hand | 34.3 | (28.3) | 49.9 | (41.2) | 36.8 | (30.5) | 0.438 | 121.0 |
| 2 | Power | Gravity | Hand | 37.1 | (29.9) | 51.1 | (41.0) | 36.3 | (29.1) | 0.410 | 124.5 |
| 3 | Power tiller | Gravity | Small Portable | 30.3 | (24.8) | 51.5 | (42.0) | 40.5 | (33.2) | 0.497 | 122.3 |
| 4 | Tractor | Gravity | Large Axial flow | 27.0 | (25.3) | 44.6 | (41.8) | 35.0 | (32.9) | 0.490 | 106.6 |
| 5 | Carabao | 4" Pump | Hand | 51.1 | (33.5) | 60.0 | (39.3) | 41.1 | (27.2) | 0.374 | 152.2 |
| 6 | Power tiller | 4" Pump | Hand | 47.7 | (31.2) | 63.8 | (41.7) | 41.3 | (27.1) | 0.372 | 152.8 |
| 7 | Power tiller | 4" Pump | Small Portable | 39.6 | (26.8) | 61.5 | (41.6) | 46.6 | (31.6) | 0.462 | 147.7 |
| 8 | Tractor | 10" Pump | Large Axial flow | 23.6 | (21.0) | 47.8 | (42.3) | 41.5 | (36.7) | 0.580 | 112.9 |
| 9 | Carabao | Rainfed | Hand | 27.4 | (36.3) | 29.3 | (38.8) | 18.8 | (24.9) | 0.332 | 75.5 |
| 10 | Power tiller | Rainfed | Hand | 24.2 | (32.1) | 27.8 | (36.9) | 23.3 | (31.0) | 0.449 | 75.3 |
| 11 | Power tiller | Rainfed | Small Portable | 19.5 | (24.1) | 34.2 | (42.2) | 27.1 | (33.7) | 0.508 | 30.8 |
| 12 | Tractor | Rainfed | Large Axial flow | 15.1 | (22.5) | 28.6 | (42.5) | 23.5 | (35.0) | 0.538 | 67.2 |
| 13 | Carabao | Upland | Hand | 14.0 | (31.5) | 17.3 | (39.0) | 13.1 | (29.5) | 0.418 | 44.4 |

mechanized system in other water regimes.

The various rice farm household groups are differently benefited by the four farm mechanization programs. The relative shares of hired labor households decline with moderate to high levels of mechanization while the share of farm operators and landowners increase so that overall income distribution worsens as indicated by the inequality measure. However, two points should be noted: a highly mechanized irrigation system (4) generates as much *absolute* income gain for hired labor as a non-mechanized rainfed system (9), and power tiller technology combined with hand threshing seems to improve the income distribution in some of the water regimes compared to using carabao.

Another observation is that while power tillers have high output and low redistributive effects, threshers and tractors, on the contrary, have high redistributive and low output effects. Inequality increases with mechanization more in the rainfed than in the irrigated systems.

**Income distribution among household classes**

The results on income distribution among household classes appear in Table 6. The rural-urban income disparity is measured by the ratio of non-farm to farm sector gain in income.

The different water regimes differ with respect to their income generating capacities. Pump irrigated systems yield the largest increase in national income, followed by gravity, rainfed and upland systems. Increasing mechanization usually results in declining income probably because of lower consumption effects among the direct beneficiaries of mechanization.

The results indicate that mechanization in general leads to greater inequalities in rural-urban income distribution. This happens first because mechanization depends on industrial sectors for the supply of machinery and second, because within the rice economy, income is redistributed in favor of household classes whose consumption patterns are biased towards luxuries produced in urban areas.

Increasing rice production in the rainfed and upland systems with or without mechanization results in the greatest increase in rural-urban income disparity, probably due to their dependence on land for the incremental output, with land's earnings, in turn, going to landowners.

**Income, Consumption, Savings and Import**

Mechanization leads to a simultaneous change in national and per capita income, consumption, savings, imports and labor's share with the results shown in Table 7. The largest increase in per capita income occurs with pump irrigation systems under low levels of mechanization, closely followed by gravity and distantly followed by rainfed and upland systems. Though for a given water regime, mechanization yields a lower level of per capita income, comparing across water regimes shows that per capita incomes under the mechanization alternative may be well over those attained

Table 6

**Income redistribution implications for household classes of a one percent increase in consumer spending for rice when demand is met from specified rice production sector**

| Sector number | Rice Production Sectors | | | Rice Farm | | Non-Rice Farm | | Non-Farm | | Ratio of non-farm to farm incremental income | Total incremental income (million ₱) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Power | Irrigation | Thresher | | | | | | | | |
| | Actual economy, 1978 income (million ₱) | | | 8,566 | | 39,808 | | 122,416 | | | |
| | | | | Absolute increase (million ₱) | Incremental share | Absolute increase (million ₱) | Incremental share | Absolute increase (million ₱) | Incremental share | | |
| 1 | Carabao | Gravity | Hand | 121.0 | (28.0) | 95.3 | (22.2) | 215.3 | (49.8) | 0.995 | 431.6 |
| 2 | Power tiller | Gravity | Hand | 124.5 | (28.4) | 94.9 | (21.6) | 218.5 | (50.0) | 0.996 | 437.9 |
| 3 | Power tiller | Gravity | Small Portable | 122.3 | (28.5) | 81.6 | (21.4) | 214.3 | (50.1) | 1.001 | 428.2 |
| 4 | Tractor | Gravity | Large Axial flow | 106.6 | (27.6) | 83.8 | (21.7) | 195.5 | (50.7) | 1.026 | 385.9 |
| 5 | Carabao | 4" Pump | Hand | 152.2 | (28.7) | 118.3 | (22.3) | 260.2 | (49.0) | 0.961 | 530.7 |
| 6 | Power tiller | 4" Pump | Hand | 152.8 | (29.0) | 115.1 | (21.8) | 259.1 | (49.2) | 0.967 | 527.0 |
| 7 | Power tiller | 4" Pump | Small Portable | 147.7 | (29.0) | 109.5 | (21.6) | 250.5 | (49.4) | 0.974 | 507.7 |
| 8 | Tractor | 10" Pump | Large Axial flow | 112.9 | (27.1) | 87.8 | (21.1) | 215.8 | (51.8) | 1.075 | 416.5 |
| 9 | Carabao | Rainfed | Hand | 75.5 | (26.0) | 66.5 | (22.9) | 148.7 | (51.1) | 1.047 | 290.7 |
| 10 | Power tiler | Rainfed | Hand | 75.3 | (27.0) | 60.1 | (21.5) | 143.8 | (51.5) | 1.062 | 279.2 |
| 11 | Power tiller | Rainfed | Small Portable | 80.8 | (27.4) | 62.6 | (21.2) | 151.2 | (51.4) | 1.054 | 294.6 |
| 12 | Tractor | Rainfed | Large Axial flow | 67.2 | (26.0) | 55.8 | (21.6) | 135.1 | (52.4) | 1.098 | 258.1 |
| 13 | Carabao | Upland | Hand | 44.4 | (24.0) | 42.3 | (22.9) | 98.4 | (53.1) | 1.134 | 185.1 |

Table 7

Income, consumption, savings, imports and compensation for employees implications of a one percent increase in consumer spending for rice when demand is met from specified rice production sector

| Sector Number | Rice Production Sectors: Power | Irrigation | Thresher | Per Capita income (₱) | National (mil. ₱) | Ratio of personal consumption expenditure/ national income | Ratio of savings and taxes/national income | Ratio of imports/ national income | Ratio of compensation for employees/ national income |
|---|---|---|---|---|---|---|---|---|---|
| | | | Actual economy, 1978 | 3,754 | 170,790 | 0.67187 | 0.32813 | 0.24366 | 0.37078 |
| | | | | (1) | (2) | (3) | (4) | (5) | (6) |
| 1 | Carabao | Gravity | Hand | 3,763.9 | 171,221 | 0.67202 | 0.32798 | 0.24362 | 0.37076 |
| 2 | Power tiller | Gravity | Hand | 3,764.0 | 171,228 | 0.67202 | 0.32798 | 0.24362 | 0.37078 |
| 3 | Power tiller | Gravity | Small Portable | 3,763.8 | 171,218 | 0.67201 | 0.32799 | 0.24362 | 0.37072 |
| 4 | Tractor | Gravity | Large Axial flow | 3,762.9 | 171,176 | 0.67200 | 0.32800 | 0.24364 | 0.37074 |
| 5 | Carabao | 4" Pump | Hand | 3,766.1 | 171,320 | 0.67206 | 0.32794 | 0.24360 | 0.37083 |
| 6 | Power tiller | 4" Pump | Hand | 3,766.0 | 171,317 | 0.67206 | 0.32794 | 0.24360 | 0.37080 |
| 7 | Power tiller | 4" Pump | Small Portable | 3,765.5 | 171,297 | 0.67204 | 0.32796 | 0.24361 | 0.37074 |
| 8 | Tractor | 10" Pump | Large Axial flow | 3,763.5 | 171,206 | 0.67199 | 0.32801 | 0.24368 | 0.37068 |
| 9 | Carabao | Rainfed | Hand | 3,760.8 | 171,080 | 0.67197 | 0.32803 | 0.24363 | 0.37082 |
| 10 | Power tiller | Rainfed | Hand | 3,760.5 | 171,069 | 0.67196 | 0.32804 | 0.24363 | 0.37079 |
| 11 | Power tiller | Rainfed | Small Portable | 3,760.9 | 171,085 | 0.67197 | 0.32803 | 0.24363 | 0.37073 |
| 12 | Tractor | Rainfed | Large Axial flow | 3,760.1 | 171,048 | 0.67195 | 0.32805 | 0.24365 | 0.37073 |
| 13 | Carabao | Upland | Hand | 3,758.5 | 170,975 | 0.67193 | 0.32807 | 0.24363 | 0.37078 |

under non-mechanized systems. The falling per capita incomes with rising mechanization is due to the low propensity to consume and high propensity to import of the main beneficiaries of the machines rather than low productivity as is the case with rainfed and upland systems.

Mechanization leads to increased savings because of an increase in profit as a proportion of value added. The rise in savings marks an increase in resource available for agricultural capital formation. However, the model does not describe how the additional savings are utilized for agricultural capital formation.

The volume of imports rise with levels of mechanization, but as income also increases, the ratio of import/income remains constant.

The systems in pump irrigation regimes generate the largest labor share compared to corresponding systems in other water regimes.

## CONCLUSIONS

The study used the 1978 national income and input-output data to derive employment, income distribution and resource utilization implications of rice farm mechanization. A number of important conclusions emerge from the study. Though the frailities of the data base and the nature of assumptions made in deriving results demand some caution in drawing conclusions, the consistency and orders of magnitude of the major findings reinforce confidence in the results. The calculated employment increase for a one percent increase in consumer spending for rice varies from 23,000 workers using the fully mechanized option under rainfed conditions to 53,000 workers using the low level of mechanization in pump irrigated systems. The increase in employment that occurs seems to depend importantly on the consumption linkages that arise from a decrease in the personal income/savings ratio and to a shift of private consumption towards more labor-intensive products. The consumption connection is usually neglected in farm employment studies. The direct increase in employment takes place in non-rice activities. The direct effect alone overestimates the true displacement of labor by 5-10 percent.

The quantitative values of the quasi-elasticities can be used by policy-makers in calculating total requirements of resources needed for carrying out a given program of rice production. One important result is that mechanization leads to a greater efficiency in resource allocation as indicated by the declining natures of quasi-elasticities with increasing levels of mechanization.

Alternative mechanization strategies benefit various rice farm households (hired labor, farm operator and landowners) in different manners. Thus, while fully mechanized systems using four-wheel tractors and large axial flow threshers are sure to divert income from hired labor to landowner, power tiller technology used with hand threshing increases labor's share.

The income gap between rural and urban sectors is found to widen with increasing intensity of mechanization. The solution to this problem requires wide dissipation of industrial activities, especially the agricultural machinery sector and its related repair services into the rural and semi-urban areas.

Mechanization leads to an increase in the savings ratio, via an increase of profit in value added. The rise in savings marks an increase in total resources available for agricultural capital formation which may lead to higher future growth in spite of a slightly lower present income. However, the present static model cannot reflect such effects.

On the basis of the above results, it can be concluded that irrigation can contribute the maximum to development of the rice sector but that farm mechanization based on power tillers and small threshers is a sound economic measure with a minimum displacement of labor. The high technology systems using big tractors and large threshers possess a clear advantage over low and medium technology systems in generating surplus from the rice sector which would otherwise be a semi-subsistence one. With proper public policies, a part of the surplus should be diverted towards agricultural capital formation so that its reinvestment might open the possibility of higher rates of employment and income growth.

Several cautionary points must be raised. The data used to generate the rice production sub-sectors were based on small sample surveys. They do not, therefore, give the true national coefficients, although they were adjusted to be consistent with the national coefficients. An improved model would result from using national data for the technical coefficients of the sub-sectors. Also, it was assumed that all four levels of mechanization give the same yield and use the same level of fertilizer and chemicals with a given irrigation system. If this is not true on a national basis, its correction would lead to different results.

# APPENDIX A

**Calculation of cost and returns in 13 systems of rice production, 1978 ***

| No. | Rice Production System: Power | Irrigation | Thresher | Location | Intermediate cost[d] (peso/hectare/season): Seed | Carabao | Fertilizer | Chemicals | Fuel or lubricants | Agricultural machinery | Factor earnings[d/] (peso/hectare/season): Hired labor | Operator | Landowner | Taxes (₱) | Total value[d] (₱) | Yield (kg) | Cropping intensity (%) | Proportion of rice produced (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1[a] | Carabao | Gravity | Hand | Central Luzon | 75 | 200 | 194 | 40 | 0 | 0 | 657 | 964 | 722 | 88 | 2940 | 3000 | 133 | 20 |
| 2[a] | Power tiller | Gravity | Hand | Central Luzon | 75 | 0 | 194 | 40 | 73 | 56 | 719 | 988 | 707 | 88 | 2940 | 3000 | 133 | 5 |
| 3[a] | Power tiller | Gravity | Small portable | Central Luzon | 75 | 0 | 194 | 40 | 85 | 82 | 564 | 1003 | 809 | 88 | 2940 | 3000 | 133 | 6 |
| 4[a] | Tractor | Gravity | Large axial flow | Central Luzon | 75 | 106 | 194 | 40 | 94 | 195 | 518 | 890 | 720 | 88 | 2940 | 3000 | 133 | 11 |
| 5[a] | Carabao | 4" pump | Hand | Laguna | 50 | 198 | 129 | 111 | 335 | 100 | 1025 | 11160 | 795 | 117 | 3920 | 4000 | 200 | 3 |
| 6[a] | Power tiller | 4" pump | Hand | Laguna | 50 | 0 | 129 | 111 | 405 | 156 | 946 | 1253 | 803 | 117 | 3920 | 4000 | 200 | 1 |
| 7[a] | Power tiller | 4" pump | Small portable | Laguna | 50 | 0 | 129 | 111 | 418 | 190 | 764 | 1209 | 932 | 117 | 3920 | 4000 | 200 | 3 |
| 8[a] | Tractor | 10" pump | Large axial flow | Mindanao | 75 | 0 | 356 | 226 | 617 | 300 | 413 | 931 | 805 | 117 | 3920 | 4000 | 200 | 1 |
| 9[b] | Carabao | Rainfed | Hand | Iloilo | 66 | 296 | 114 | 10 | 0 | 0 | 541 | 535 | 340 | 58 | 1960 | 2000 | 105 | 38 |
| 10[b] | Power tiller | Rainfed | Hand | Iloilo | 66 | 0 | 114 | 10 | 73 | 61 | 475 | 645 | 458 | 58 | 1960 | 2000 | 105 | 2 |
| 11[b] | Power tiller Tractor | Rainfed | Small portable | Iloilo | 66 | 0 | 114 | 10 | 85 | 78 | 356 | 664 | 541 | 58 | 1920 | 2000 | 105 | 2 |
| 12[b] | Power tiller | Rainfed | Large axial flow | Iloilo | 66 | 126 | 114 | 10 | 102 | 198 | 267 | 550 | 469 | 58 | 1960 | 2000 | 105 | 2 |
| 13[c] | Carabao | Upland | Hand | Average | 71 | 260 | 18 | 8 | 0 | 0 | 265 | 320 | 246 | 37 | 1225 | 1250 | 85 | 6 |

Source:
a Quantity data from Herdt and Lacsina 1976.
b Quantity data from Herdt and Gonzales 1980.
c Quantity data from Dozina and Herdt 1974.
d Price data from BAEcon.

*See text for methodology.

## APPENDIX B

**Calculation of cost and returns in five agricultural machinery manufacturing sectors, 1978 ***

| No. | Agricultural machinery manufacture sectors | | | Intermediate cost (Peso/unit) | | | | Value added (peso/unit) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Type | Description | Horse power | Basic metal and purchased material | Paints and chemicals | Rubber products | Engine[c] | Labor | Other | Taxes (P) | Selling price |
| 1 | Power tiller[a] | 2–wheel | 6–8 | 4447 | 58 | 293 | 2500 | 950 | 3582 | 1170 | 13000 |
| 2 | Tractor | 4–wheel | 35 | – | – | – | 70800[d] | 2615 | 38185 | 8400 | 120000 |
| 3 | Irrigation[b] pump | 4" 0 axial flow | 5 | 1140 | 61 | 26 | 1760 | 994 | 1744 | 576 | 6300 |
| 4 | Portable thresher | TH–6 IRRI design | 7 | 1683 | 55 | 26 | 2150 | 530 | 2888 | 468 | 7800 |
| 5 | Large axial flow thresher | TH–8 IRRI design | 12 | 3947 | 65 | 725 | 4500 | 1326 | 5587 | 850 | 17000 |

[a]With attachments.

[b]Includes installation cost.

[c]Briggs and Stratton.

[d]c.i.f. price of fully assembled tractors.

Source: Industrial Engineering Unit of Department of Ag. Engineering, IRRI

*See text for methodology.

## APPENDIX C

**Gross output and value added by sectors of the Input-Output Table, 1978 (in millions of pesos and at producers' prices).**

| Sectors | Gross output | Value added |
|---|---|---|
| (1) Rice (paddy production and milling) | 18,984 | 8,554 |
| (2) Agricultural crops, livestock, forestry & fishery | 37,743 | 30,310 |
| (3) Other agricultural production and service activities | 10,593 | 9,445 |
| (4) Mining and quarrying | 4,996 | 3,374 |
| (5) Processed foods | 42,304 | 14,399 |
| (6) Sugar milling and refining | 7,896 | 2,698 |
| (7) Textiles and footwear | 14,660 | 4,130 |
| (8) Lumber and wood products | 6,669 | 1,896 |
| (9) Paper products and printing | 3,723 | 1,859 |
| (10) Leather products | 134 | 62 |
| (11) Rubber products | 1,281 | 442 |
| (12) Fertilizer | 1,394 | 427 |
| (13) Chemicals | 9,574 | 3,171 |
| (14) Petroleum products | 11,221 | 3,815 |
| (15) Cement | 2,664 | 700 |
| (16) Other non-metallic mineral products | 1,536 | 699 |
| (17) Basic metal and metal products | 10,320 | 3,490 |
| (18) Agricultural machinery | 367 | 191 |
| (19) Machineries except electrical and miscellaneous manufactures | 2,087 | 1,135 |
| (20) Electrical machinery and apparatus | 2,580 | 1,223 |
| (21) Transport equipment | 3,938 | 2,206 |
| (22) Electricity | 3,223 | 1,467 |
| (23) Gas manufacture and distribution | 17 | 8 |
| (24) Water services | 337 | 176 |
| (25) Construction | 21,796 | 12,605 |
| (26) Trade | 32,350 | 26,566 |
| (27) Banking and other financial institutions | 16,372 | 13,390 |
| (28) Transport services | 14,336 | 8,284 |
| (29) Medical, health and education | 4,555 | 2,817 |
| (30) Other business services | 23,612 | 11,898 |
| Total | 310,358 | 170,477 |

# FARM MECHANIZATION STRATEGIES IN AN ECONOMY-WIDE MODEL: INDONESIA

C.S. Ahammed and B. Duff*

## INTRODUCTION

Many empirical studies examining farm mechanization in developing countries are concerned with estimating the on-farm labor displacement and income distribution effects.[1/] However, there are many indirect effects that are not captured when looking only at farm level data. Some arise from linkages between the farm and non-farm sectors and between the farm and the household. The importance of these production and consumption linkages in the agricultural growth process has been emphasized by a number of scholars (Johnston and Kilby 1975, Mellor 1976). They point out that the choice of development strategy establishes a structure of linkages and incentives which exert a continuing influence on the economy. The problem of strategy choice can be investigated by a historical evaluation of the experience of a variety of countries. Alternatively, it can be investigated by simulating the effects of choice in one country under a representative set of behavioral and structural relationships. This study uses the latter approach and presents a quantitative assessment of the effects of alternative rice production mechanization strategies on employment, income distribution, savings and import demand in Indonesia.

Production and consumption linkages arise because modern farm production technologies require increased purchase of current and capital inputs and because the resulting rise in farm income will lead to a large increase in consumption expenditure.[2/] The strength of the linkages depends on the distribution of income from rice production and the consumption propensities of various earners. Import substitution in production and consumption also affects the linkages. A variant of the Social Accounting Matrix (SAM) model is developed, to explore these effects. Weisskoff calculated employment effects for alternative import substitution and export promotion strategies using conventional input-output analysis (1971). Thorbecke et. al. checked the feasibility of full employment (1972) and Krishna measured direct and indirect employment effects of growth and technical change in the farm sector using a conventional input-output model (1975). Paukert et.al. (1975) used SAM methodology later developed by Pyatt and Round (1977 and 1979) to present empirical results of the links between changes

1/ See for example the studies reviewed by Eicher and Witt (1964) and Duff (1978).

2/ Mellor (1976) stresses the consumption linkages in a somewhat broader development context.

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in income distribution and changes in employment. Bell and Hazell used the SAM approach to measure indirect effects of an agricultural investment project on its surrounding region (1980). These earlier approaches are extended by identifying and measuring the effects of a series of different technologies for rice production.

## METHODOLOGICAL CONSIDERATIONS[3/]

The basis for the analysis is the national input-output matrix for Indonesia. Alternative technological strategies for rice production are reflected by separating the rice sector in that matrix into 18 subsectors, differing by level of farm mechanization and associated water-topography (Table 1). In a similar way the agricultural machinery sector is separated into 5 subsectors comprised of 7 rice production machines (Table 2). Five groups of consumers, with different consumption parameters and different resource ownership patterns are defined.

Specifying which system produces what amount of final demand, the model uses semi-closed input-output relations to compute the domestic production and the intermediate imports required to meet the demand. The factor shares of production determine the distribution of income among owners of factors which in turn affects the volume and pattern of private consumption and savings. Finally, the model computes the corresponding employment and personal income of each consumer group. Comparison of the results obtained with varying proportions of total rice area cultivated by the 18 subsectors provides a measure of the effect of different patterns of technological innovation.

The Indonesian Bureau of Statistics' (BPS) 66 sector input-output model (1980) was consolidated into a 33 x 33 sector model. The disaggregation of the rice and agricultural machinery sectors were added to that 33 x 33 matrix to give an input-output table of 54 x 54 sectors. The augmented matrix (54 x 54) met two criteria: the individual technological coefficients in the rice and farm machinery subsectors had to be consistent with known differences and had to aggregate into national technological coefficients (for rice or farm machinery) equal to the sectoral coefficient that appears in the original input-output table.

Five household classes are distinguished to incorporate the income distribution, consumption, saving and import substitution effects of technological innovations. For rice farm households, the definitions rest on endowments of land, labor and capital; the other household classes are defined as non-rice farm households and non-farm households.

The first class, hired labor households, derive their income from labor services in rice farming. Landowner households include farmers as well as landlords. Their incomes consist of the returns from land and capital. Farm operator households are defined as renters of land, and obtain earnings from

[3/] The methodology described here is a slight modification of that used in an earlier, similar analysis of the impact of mechanization in Philippine rice production (Ahammed and Herdt 1983b).

Table 1

Eighteen technological options for rice production in Indonesia

| Irrigation | Land preparation | Weeding & threshing | Harvesting & threshing | Assumed yield kg/ha | Assumed cropping intensity | Assigned proportion of paddy produced |
|---|---|---|---|---|---|---|
| Upland | Carabao | Manual | Manual | 1,500 | 90 | 6 |
| Rainfed | Carabao | Manual | Manual | 2,000 | 90 | 31 |
| Rainfed | Power tiller | Manual | Manual | 2,000 | 100 | 8 |
| Gravity I | Carabao | Manual | Manual | 3,800 | 200 | 20 |
| Gravity I | Carabao | Weeder & Trans–planter | Reaper & Thresher | 3,800 | 220 | 1 |
| Gravity I | Power tiller | Manual | Manual | 3,800 | 220 | 3 |
| Gravity I | Power tiller | Manual | Reaper & thresher | 3,800 | 230 | 1 |
| Gravity I | Power tiller | Weeder & trans–planter | Reaper & thresher | 3,800 | 240 | 1 |
| Gravity II | Carabao | Manual | Manual | 4,800 | 250 | 18 |
| Gravity II | Carabao | Weeder & trans–planter | Reaper & thresher | 4,800 | 275 | 1 |
| Gravity II | Power tiller | Manual | Manual | 4,800 | 275 | 3 |
| Gravity II | Power tiller | Manual | Reaper & thresher | 4,800 | 287 | 1 |
| Gravity II | Power tiller | Weeder & trans–planter | Reaper & thresher | 4,800 | 300 | 1 |
| Pump | Carabao | Manual | Manual | 4,800 | 250 | 1 |
| Pump | Carabao | Weeder & trans–planter | Reaper & thresher | 4,800 | 275 | 1 |
| Pump | Mini tractor | Manual | Manual | 4,800 | 275 | 1 |
| Pump | Mini tractor | Manual | Reaper & thresher | 4,800 | 287 | 1 |
| Pump | Mini tractor | Weeder & trans–planter | Reaper & thresher | 4,800 | 300 | 1 |

Table 2

**Seven agricultural machines making up five machinery sectors**

| Sub–sector | Type of machinery | Description | Cost to Farmer (Rp) | Horse power |
|---|---|---|---|---|
| 1 | Power tiller | 2–wheel with rotavator | 1,250,000 | 6 (Diesel) |
| 2 | Mini tractor | 4–wheel and rotavator | 4,500,000 | 13-14 (Diesel) |
| 3 | Weeder | Manually operated IRRI type | 8,000 | – |
| 3 | Transplanter | Manually operated IRRI type | 180,000 | – |
| 4 | Reaper | HT–IRRI type | 200,000 | 6 (Gasoline) |
| 4 | Thresher | TH–6 IRRI type | 500,000 | 5 (Gasoline) |
| 5 | Irrigation pump | 6 inch–Axial flow | 365,000 | 5 (Gasoline) |

both capital and labor. Incomes of non-rice farm and non-farm households are assumed to depend on gross output produced in these sectors.

## The Model

Five groups of equations comprise the model: production and household consumption, imports, saving, income and employment.

The first set achieves material balances among all production sectors and household classes. The equations are built around fixed input-output and household expenditure coefficients. Distribution of consumption expenditures (for domestic items) by household classes result from the assumptions of a consumption function in which the expenditure share of a given commodity in the total (pre-tax) income of the household remains constant.

Imports are disaggregated in two groups: imports for intermediate use and imports for consumption. Both groups of imported goods are fixed in proportion to sectoral outputs and household incomes respectively.

Saving is defined as a residual obtained by substracting consumption expenditure on domestic and imported items from (pre-tax) gross income.

It therefore follows that total expenditure on private consumption (domestic and imported items) plus private savings on each household class is equal to the total income of the class.

Gross value added in each of the rice systems is allocated as payments to operators, laborers and landlords. These payments determine income for the first, second and third groups of household classes. Non-rice farm income and non-farm income are assumed to be fixed proportions of total output in these sectors. Income components generated for each of the household classes per unit of sectoral output produced are assumed to remain constant.

Employment in each sector is assumed to be determined by a fixed sectoral labor-output ratio. Total employment is obtained by summing employment of all sectors.

In its most general formulation the variant of the SAM model discussed above can be written as

(1) $Q \cdot R = Z$

where Q is a 62 x 62 square matrix of structural coefficients,

R is a 62 x 1 column vector of the endogenous variables,

Z is a 62 x 1 column vector of the exogenous variables.

The solution is obtained as

(2) $R = Q^{-1} \cdot Z$

The components of the Q·R and Z matrices are:

(3) $$\underset{Q}{\left[\begin{array}{c|c|c|c} I-A & 0 & -C & 0 \\ \hline -A_m & & -C_m & \\ & I & & 0 \\ 0 & & -C_s & \\ \hline -A_k & 0 & I & 0 \\ \hline -A_L & 0 & 0 & I \end{array}\right]} \underset{R}{\left[\begin{array}{c} X \\ \hline M \\ \\ S \\ \hline Y \\ \hline L \end{array}\right]} = \underset{Z}{\left[\begin{array}{c} F \\ \hline \\ 0 \\ \\ \hline 0 \\ \hline 0 \end{array}\right]}$$

where X is a 54 x 1 vector of outputs, $x_j$

A is a 54 x 54 square matrix of technological coefficients with elements $a_{ij}$'s defined as

(4) $a_{ij} = x_{ij}/x_j$ (i, j = 1,2, - - -,56)

$x_{ij}$ is the intermediate delivery of sector i to sector j.

Y is the 5 x 1 vector of household class incomes, $y_k$'s

$C_c$ is a 54 x 5 rectangular matrix of domestic consumption coefficients with elements $c_{ik}$'s defined as

(5) $c_{ik} = e_{ik}/y_k$ (i = 1,2, . . . 54, k = 1,2, . . . ,5)

where $e_{ik}$ is the expenditure on private consumption of domestic commodity i by household class k.

F is 54 x 1 vector of exogenous final uses like government consumption, stocks, exports and imports.

$A_m$ is a 1 x 54 vector of intermediate import coefficients with elements $a_{mj}$'s defined as

(6) $a_{mj} = m_j/x_j$

where $m_j$ is intermediate imports by sector j.

$C_m$ is a 1 x 5 vector of private consumption of imported goods defined as

(7) $m_{ck} = e_{mk}/yk$

where $e_{mk}$ is private consumption of direct imports in the kth household class.

$C_s$ is a 1 x 5 vector of private savings with elements $c_{sk}$'s defined as

(8) $c_{sk} = \dfrac{s_k}{y_k}$

where $s_k$ is private savings for the kth household class defined as a residual

(9) $s_k = y_k - \sum_{i=1}^{54} c_{ik} - c_{mk}$

$A_k$ is a 5 x 54 rectangular matrix of income coefficients with elements $a_{kj}$'s defined as

(10) $$a_{kj} = \frac{y_k}{x_j}$$

M is total imports.

S is total savings.

L is total labor employment.

$A_1$ is a 1 x 54 vector of labor coefficients with elements $a_{1j}$'s defined as

(11) $$a_{1j} = l_j/X_j$$

where $l_j$ is employment in jth sector.

The elements of the main diagonal of matrix Q are positive. The remaining non-zero elements are negative and with the exception of the import coefficients are smaller than one. Thus, it can be expected that matrix Q will have an inverse.

**The Modified Model**

The SAM model discussed above is based on the assumptions of perfectly elastic supplies in all sectors. This assumes that each sector faces constant average costs as well as perfectly elastic supplies of all inputs and resources. This may not be very unrealistic for imports, and small scale manufacturing and service activities, but it may not be a reasonable assumption for primary activities and capital intensive manufacturing and infrastructure services. These sectors cannot easily respond to increased demand in the short run, and much of the increased demand is likely to be translated into price increases, at least until sufficient investment has been made to increase supplies. One feature of the Bell-Hazell (1980) study was a modification of input-output methods to enable a choice of fixing either the output or the exports level for each sector. Following their method one can choose to assume for each sector whether supplies are perfectly elastic or perfectly inelastic. The latter assumption may be more relevant for primary activities and capital intensive non-farm activities, whereas the perfectly elastic assumption may be retained for other sectors.

Let the primary activities and capital intensive non-farm sectors be denoted by subscript p (other farm-food crops, agricultural crops, carabao services, fishery and livestock products, forestry, mining and quarrying, sugar refinery, paper products and printing, petroleum products, cement, basic metal and metal products, electricity and gas manufacture and irrigation investment) and rest sectors by subscript v.[4] The following rearrangement of our original model (Eq. 3) can be made.

$$(12)\quad \left[\begin{array}{c|c|c|c|c} I-A_{vv} & 0 & 0 & -C_{cv} & 0 \\ \hline -A_{pv} & -I & 0 & -C_{cp} & 0 \\ \hline \begin{array}{c} -A_{mv} \\ 0 \end{array} & 0 & I & \begin{array}{c} -C_{m} \\ -C_{s} \end{array} & 0 \\ \hline -A_{kv} & 0 & 0 & I & 0 \\ \hline -A_{1v} & 0 & 0 & 0 & I \end{array}\right] \left[\begin{array}{c} X_v \\ \hline F_p \\ \hline \begin{array}{c} M \\ S \end{array} \\ \hline Y \\ \hline L \end{array}\right]$$

$$\left[\begin{array}{c|c|c|c|c} I & A_{vp} & 0 & 0 & 0 \\ \hline 0 & -I+A_{pp} & 0 & 0 & 0 \\ \hline 0 & \begin{array}{c} A_{mp} \\ 0 \end{array} & 0 & 0 & 0 \\ \hline 0 & A_{kp} & 0 & 0 & 0 \\ \hline 0 & A_{1p} & 0 & 0 & 0 \end{array}\right] \left[\begin{array}{c} F_v \\ \hline X_p \\ \hline 0 \\ \hline 0 \\ \hline 0 \end{array}\right]$$

Equations 3 and 12 are utilized to obtain empirical results.

To measure employment generated by the consumption and production linkages of the modern technologies in rice proceed as follows: First

4/ Unlike other primary activities, rice production has a perfectly elastic supply. This exception is dictated by our method of model simulation — — an exogenous increase in rice consumption met from a given rice sub-sector.

simulate the complete model as expressed in Equations 3 and 11 with an exogenous increase in consumer demand for rice fully met from the first subsector. The matrix is then inverted and finally post-multiplied by the constant vector (matrix) of exogenous variables in order to obtain the solution vector. The same process is followed for each of the 18 subsectors. This gives 18 simulations for 18 subsectors; in each, the $c_{ik}$ parameters for the relevant rice sub-sector i are increased to accommodate the shift in consumption expenditure in rice. Numerical values computed in selected pairs of simulations are subtracted from each other to measure the change that would occur if production took place in one rather than another subsector. Then, consider a subset of the model relationships containing equations for production and employment[5/] and simulate the effect of an exogenous increase in consumer demand for rice fully met from each subsector in turn. Again there are 18 simulations; in each, the household consumption components in vector F are increased to reflect the shift in consumption for the relevant rice sub-sector. Comparison of employment in two simulations allow total effects to be decomposed into production and consumption effects.

The study is a static comparative simulation exercise, measuring employment generated by consumption and production linkages under alternative assumptions about water control, topography and degrees of mechanization. A system of exclusively linear homogenous equations is used which allows solutions by simple matrix inversion operation.

The most important limitations of the model are assumptions of a fixed coefficient production function, unitary elasticities of demand, constant returns to scale, free labor force resource and no capacity limitations, and no balance of payment limitations.

## DESCRIPTION OF DATA

Three alternative techniques of land preparation are specified in the rice production systems: carabao (water buffalo), power tiller and mini-tractor. Two weeding methods are included: manual and human-powered mechanical weeder. Two transplanting methods, manual and human-powered mechanical transplanter, two reaping methods, manual and power-driven reaper, and two threshing techniques, manual and power-driven mini-thresher, are included. These are combined to form five successively higher levels of mechanization within four water regimes – rainfed, simple gravity (gravity I), improved gravity (gravity II) and pump. The first is non-mechanized, the fifth is fully mechanized, while the second, third and the fourth are intermediate. One additional non-mechanized dry land system is included. Input-output data on the systems were based on data obtained from a number of farm level studies by the Agronomy department of Indonesia's Central Research Institute of Agriculture (CRIA 1981), the Survey Agro-economy (SAE 1980) and Biro Pusat Statistics (BPS 1978, 1980 and 1981).

5/ The vector of household consumption is excluded from the first set relationships and household consumption is added to the final demand vector F.

The cropping intensity indices for the rice subsectors are shown in Table 1. They were computed on the assumption that while power tillers and mini tractors increase cropping intensity by 10 percent, weeder, transplanter, reaper and thresher each increase cropping intensity by 2.5 percent.

A budget was developed for each of the rice production systems, showing the breakdown of costs and the earnings accruing to hired labor, farm operator, and landowner. Total value of output was allocated to intermediate inputs, labor earnings, return to land, taxes and operator's residual. Intermediate inputs were separated into seed, carabao, fertilizer, other chemicals, fuel and lubricants and machinery.

Cost of agricultural machinery use was separated into (i) depreciation, (ii) returns to capital, (iii) fuel and lubricants, (iv) repair and (v) labor costs. Repair costs were assumed to consist of labor and capital in the same proportion as for the original machine.

The returns to land, labor and capital are apportioned to household classes in the following manner. Landowners' income equals rent on land, 50 percent of capital consumption and family labor allowances. Capital consumption allowance includes returns to capital for both the machinery and the spare parts plus interest charges. Income of hired labor households is the value added by hired labor. The income of operator households correspond to the residual 50 percent of capital consumption and family labor allowances. Indirect taxes are subtracted from each cost component and aggregated to show indirect taxes collected from rice production. Tax and tariff rates on agricultural inputs and machinery were obtained from the tariff and customs code of Indonesia.

A budget showing intermediate and primary costs involved in the construction of each of the 5 agricultural machines was developed based on data obtained from the Sub-directorate of mechanization, (Ditprod-IRRI), Indonesia. Small-scale machines like power tillers, threshers, weeders, transplanters, reapers are domestically manufactured with imported engines, while mini-tractors and irrigation pumps are imported on either partly or a completely knockdown basis.

The data on consumption patterns of households were obtained from the 1975 Family Income and Expenditure Survey of the Survey Social Economi Nasional (1976). The five household classes in the model are assumed to correspond to five income classes in the survey: landowners with income range of Rp 40,000-50,000 (the highest 5 percent of rural households), operators with income ranging from Rp 10,000-15,000 (the median group of rural households), hired labor with income range of Rp 1,000-5,000 (the lowest 5 percent of rural households), non-rice farm households with income range of Rp 15,000 – 20,000 and non-farm households with income range of Rp 20,000 – 25,000 (average income of urban households). The model requires distinguishing consumption expenditure on each item by household classes. For this purpose, consumption items were separated from the original 18 categories of the 1976 Family Income and Expenditure survey into a 33 category breakdown to correspond to the 1978 Input-Output table.

Import data are taken from the 1980 Foreign Trade Statistics of Indonesia published by BPS. Information on imports for intermediate uses by sectors were obtained from the 1980 input-output accounts of Indonesia. The data on import propensities of consumption for different household classes are estimated from the 1976 Family Income and Expenditure Survey.

Savings and taxes include personal plus corporate savings and direct plus indirect taxes. Data on aggregate savings and taxes are obtained from National Income Accounts (BPS 1981). The aggregate savings and tax figures are disaggregated into separate household classes using the 1976 Family Income and Expenditure survey.

Data on labor force are taken from the National Labor Force Survey (SAKERNAS 1976) and the Intercensal Population Survey (SUPAS 1976). The data include both unemployed and employed labor force.

## MODEL SIMULATIONS AND RESULTS

Model simulations consider an increase in consumer spending for rice equal to the amount produced on 1,000 ha. of land in each rice production subsector in turn. The difference in the results obtained by increasing the output from one sector compared to another provides an indicator of the impact of the selected sector. Due to space limitations the results of 12 selected comparisons, arranged in ascending order of mechanization are presented so that a comparison within a given water regime yields the production and consumption effects of mechanization. Comparison across water regimes reflects the production and consumption effects of irrigation (not shown).

### Employment Effects of Mechanization

Employment in the rice sector consists of both family and hired labor. However as non-rice employment is calculated from labor coefficients in the national input-output table it refers to hired labor only. A change in employment arising from mechanization is the consequence of production and consumption effects. The production effect is separated into three components: first-round direct effects that refer to initial changes in employment in the rice sector due to machine use, equilibrium direct effect that refers to employment in the rice sector arising from subsequent production and consumption linkages for rice, and indirect effects that show labor employment impacts in the non-rice sector by 'backward' and 'forward' production linkages. Consumption effects are indirect by nature and signify change in employment in non-rice sectors arising from the income flow from a given level of technology taking into account possibilities of import substitution in consumption.

### Power Tiller and Mini Tractor

Consumption and production effects of employment that arise from mechanization under various water regimes are shown in Table 3. The results (first row) indicate that if the increased rice hectarage is attained by increasing production from an irrigated sub-sector using a power tiller rather than a carabao, employment would increase five to fifteen times that of a similar change in land preparation power source under rainfed conditions. As expected the first-round direct employment effect of moving from carabao to power tiller/mini tractor is always negative and the decline is largest in rainfed systems. Equilibrium direct effect comprising subsequent production and consumption linkages for rice demand is always positive and offsets the intial decline in employment. The equilibrium direct effect is strongest in pump irrigated regimes and weakest in rainfed systems. The indirect production effect showing labor employment in non-rice sectors is generally positive and increases with irrigation intensification. The negative direct effect of adopting mini tractors in pump irrigation systems is explained by high import linkages of inputs. The increase in employment seems to depend importantly on the consumption linkages, which are much higher in the irrigated regimes because of increased use of hired labor in land preparation. If the consumption linkages were ignored, as happens in conventional analysis, the net effect on employment would appear to be negative; and this would be true even in irrigated regimes. This dramatizes the need for inclusion of consumption linkages in evaluating potential new technologies.

**Weeder and Transplanter**

The second row in Table 3 shows the production and consumption effects of adopting weeder and transplanters. In contrast to the previous case, here both the direct effects and the portion of the indirect effect traceable to consumption effects is negative and offsets any increase in employment due to the indirect production effect. This is because weeders and transplanters lead to a decline in hired labor and because the landless have higher consumption propensities than other classes. However, looking across columns shows that the decline in employment associated with weeder and transplanter use diminishes with increasing level of irrigation. This happens as the decline in consumption effects become smaller while at the same time the increase in the production effect becomes greater in more intensive irrigated regimes. Improved irrigated regimes with more income in a better distribution have far more consumption linkages than less sophisticated irrigation systems.

**Threshers and Reapers**

The third row shows the production and consumption linkages of employment effects in different water regimes resulting from the adoption of threshers and reapers. It appears that the decline (increase) in net employment from this transformation is lower (higher) than that occurring from a substitution of manual weeding and transplanting by weeders and transplanters. The decline in direct employment is also lower than the previous case

Table 3

Employment effect of mechanization corresponding to a 1,000 hectare change in paddy land from one subsector to another

Change in Employment (Man-years)

| Change Examined In Rice Production | Rainfed: Direct: First Round (1) | Rainfed: Direct: Equilibrium (2) | Rainfed: Indirect: Production (3) | Rainfed: Indirect: Consumption (4) | Rainfed: Total (5) | Gravity I: Direct: First Round (6) | Gravity I: Direct: Equilibrium (7) | Gravity I: Indirect: Production (8) | Gravity I: Indirect: Consumption (9) | Gravity I: Total (10) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. Carabao to power tiller/mini tractor (weeding, transplanting, reaping & threshing are done manually before and after change) | –46.8 | 121.1 | 2.5 | 18.0 | 94.8 | –7.2 | 214.0 | 22.5 | 304.6 | 533.9 |
| 2. Hand weeding and transplanting to weeder & trans– planter (land pre– paration, reaping & threshing are done mechanically before and after change) | – | – | – | – | – | –23.7 | –444.8 | 9.5 | –40.9 | –499.9 |
| 3. Hand threshing and harvesting to thresher and reapers (land preparation is mechanical while weeding and trans– planting are manual) | – | – | – | – | – | –24.8 | –383.7 | 10.8 | –15.5 | –413.2 |

| Change Examined In Rice Production | Gravity II: Direct: First Round (11) | Gravity II: Direct: Equilibrium (12) | Gravity II: Indirect: Production (13) | Gravity II: Indirect: Consumption (14) | Gravity II: Total (15) | Pump: Direct: First Round (16) | Pump: Direct: Equilibrium (17) | Pump: Indirect: Production (18) | Pump: Indirect: Consumption (19) | Pump: Total (20) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. Carabao to power tiller/mini tractor (weeding, transplanting, reaping & threshing are done manually before and after change) | –36.0 | 322.6 | 46.6 | 1132.5 | 1465.7 | –9.0 | 631.1 | –79.2 | 883.7 | 1427.6 |
| 2. Hand weeding and transplanting to weeder & trans– planter (land pre– paration, reaping & threshing are done mechanically before and after change) | –59.4 | –417.2 | 28.9 | –31.7 | –479.4 | –22.9 | –89.6 | 14.9 | 290.3 | 192.7 |
| 3. Hand threshing and harvesting to thresher and reapers (land preparation is mechanical while weeding and trans– planting are manual) | –31.5 | –312.4 | 29.8 | –50.2 | –364.3 | –27.7 | –78.1 | 10.25 | 319.37 | 223.8 |

implying that employment in the rice sector remains relatively high.

Looking row-wise across Table 3 it appears that the combined employment effect of introducing power tillers/mini tractors, weeders, transplanters, reapers and threshers increase from simple to improved gravity to pump irrigation. The implications of the results in Table 3 are that in most cases micro-studies using farm employment data overestimates the net displacement of labor associated with mechanization. However, the indirect consumption effects may either reinforce the direct labor displacement effect or offset it, depending on the consumption patterns of the household classes who receive increased income. It is evident that the higher the level of mechanization, the larger is the gain from improved irrigation. Thus low productivity caused by poor water control and inadequate inputs is responsible for low employment, not mechanization. The indirect production effects increase with increasing mechanization for a given irrigation regime indicating that production linkages play a greater role as mechanization proceeds.

**Income Effect of Mechanization**

Table 4 indicates that meeting increased rice demand by moving 1,000 hectares from carabao to power tiller/mini tractor leads to an increase in hired labor income in irrigated regimes which is much higher than in rainfed systems. Operator and land owner income is slightly higher in improved gravity rather than in pump irrigation. The income of hired labor increases progressively from simple to improved gravity and to pump irrigation.

**Weeder, Transplanter, Reaper and Thresher**

Using weeders and transplanters rather than manual weeding and transplanting has the largest impact on hired labor income, even more than the change from manual threshing and harvesting to thresher and reaper. Operator farmers derive the greatest benefit from these transformations. As with employment, the decline in hired labor income diminishes with increasing irrigation. Also, the increase in income for operator and land owner is generally higher in intensive irrigated regimes.

Hired labor gains more or loses less, relative to land owners and operators, the higher the level of irrigation. Looking row-wise across the table, the combined effect of all machines on income of household classes becomes more favorable with intensive irrigated systems. On the other hand, increased productivity and labor intensity can offset the inequitable effects of mechanization.

**Sector-Wise Incremental Production**

Table 5 shows sector-wise, the incremental production patterns for selected set of simulations. Thus, if the increased rice demand is met by increasing production from the modernized sector (subsector 10) involving

Table 4

Income effect of mechanization corresponding to a 1,000 hectare change in paddy land from one subsector to another

| Change Examined In Rice Production | Change in Income ( 000 Rupiahs) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Rainfed | | | Gravity I | | | Gravity II | | | Pump | | |
| | Hired Labor (1) | Operator (2) | Land Owner (3) | Hired Labor (4) | Operator (5) | Land Owner (6) | Hired Labor (7) | Operator (8) | Land Owner (9) | Hired Labor (10) | Operator (11) | Land Owner (12) |
| 1. Carabao to power tiller/mini tractor (weeding, trans–planting and threshing are done manually before and after change) | 3,874 | 4,618 | 5,451 | 51,218 | 62,204 | 62,888 | 85,072 | 92,424 | 88,777 | 108,917 | 69,081 | 93,245 |
| 2. Hand weeding and transplanting to weeder & trans–planter (land preparation, reaping & threshing are done mechanically before and after change) | – | – | – | –44,859 | 43,242 | 27,349 | –40,848 | 67,595 | 52,816 | –24,176 | 89,158 | 39,688 |
| 3. Hand threshing and harvesting to thresher and reapers (land preparation is mechanical while weeding and trans–planting are manual) | – | – | – | –18,541 | 26,252 | 25,204 | –12,404 | 35,709 | 29,342 | –12,493 | 52,223 | 49,241 |

Table 5

**Gross output by sectors of the input-output table, 1980 (in million Rupiahs and at producer's prices)***

| Sectors | GROSS OUTPUT Actual economy | Subsector 2 | Subsector 4 | Subsector 10 |
|---|---|---|---|---|
| . Rice | 3130.4 | 3458.0 | 4783.1 | 6229.5 |
| . Other Farm Food Crops | 1323.8 | 1323.8 | 1323.8 | 1323.8 |
| . Other Agricultural Crops | 981.2 | 981.2 | 981.2 | 981.2 |
| . Livestock Service and Activities | 21.9 | 21.9 | 21.9 | 21.9 |
| . Fisheries & Livestock Products | 840.9 | 840.9 | 840.9 | 840.9 |
| . Forestry | 359.5 | 359.8 | 359.8 | 359.8 |
| . Mining and Quarrying | 2651.9 | 2651.9 | 2651.9 | 2651.9 |
| . Processed Foods | 899.4 | 904.8 | 957.4 | 1074.6 |
| . Sugar and Refinery | 136.9 | 136.9 | 136.9 | 136.9 |
| . Textiles and Footwaer | 604.7 | 608.8 | 646.5 | 734.7 |
| . Wood and Wood Products | 115.4 | 115.7 | 117.8 | 122.5 |
| . Paper Products and Printing | 121.2 | 121.2 | 121.2 | 121.2 |
| . Fertilizer | 35.0 | 36.0 | 58.3 | 107.8 |
| . Chemicals | 208.6 | 210.3 | 229.1 | 281.0 |
| . Petroleum Products | 340.1 | 340.1 | 340.1 | 340.1 |
| . Rubber Products | 43.5 | 43.7 | 46.3 | 52.0 |
| . Other Nonmetallic Mineral Products | 95.8 | 95.9 | 97.3 | 100.2 |
| . Cement | 34.4 | 34.4 | 34.4 | 34.4 |
| . Basic Metal & Fabricated Metal Products | 232.4 | 232.4 | 232.4 | 232.4 |
| . Agricultural Machinery & Repair | 10.4 | 10.8 | 10.9 | 13.3 |
| . Electrical Machinery | 111.5 | 109.5 | 116.2 | 126.8 |
| . Transport Machinery | 717.5 | 717.7 | 738.9 | 785.2 |
| . Other Manufacturing Industries | 37.3 | 37.4 | 39.0 | 43.0 |
| . Electricity, Gas & Water Services | 164.6 | 164.6 | 164.6 | 164.6 |
| . Irrigation Investment | 94.7 | 94.7 | 94.7 | 94.7 |
| . Other Construction | 1892.0 | 1892.4 | 1894.7 | 1899.0 |
| . Trade | 2138.1 | 2142.3 | 2165.2 | 2209.8 |
| . Restaurants and Hotels | 584.8 | 585.1 | 586.9 | 590.4 |
| . Transport and Communication Services | 1227.1 | 1229.5 | 1241.6 | 1265.1 |
| . Financial Services | 289.0 | 291.8 | 304.2 | 326.6 |
| . Business and Real State Services | 454.5 | 454.7 | 456.1 | 458.9 |
| . Social, Public Administration | 1113.4 | 1113.5 | 1114.0 | 1115.0 |
| . Recreation and Household Services | 511.1 | 511.5 | 513.6 | 517.3 |
| TOTAL | 21523.3 | 21873.2 | 23420.9 | 25356.5 |

* Consumption is increased in each Subsector of rice by an amount equal to the added production of rice arising from a thousand hectare increase in paddy cultivation.

improved gravity irrigation, carabao, weeder, transplanter, reaper and thresher gross output rises by 3833.2 million rupiahs. Both consumption and production linkages account for the incremental production: rice by 81 percent, processed food by 5 percent, textiles and footwear by 3 percent, fertilizer by 2 percent, chemicals by 2 percent, manufacturing sector output by 3 percent, and construction and trade by 3 percent of the total incremental production simulation. The above pattern indicates that among other things, demand for food is likely to increase with modernization, even though the proportion of incremental income spent on food may decline as income increases. Inputs used in rice production (fertilizer, chemicals, etc.) also show some increase in production.

### Savings and Demand for Import

Table 6 shows generation of savings and demand for imports under alternative mechanization strategies. From the table it appears that savings are higher in the more intensive mechanized sector in a given water regime. This happens because the increase in income for land owners is higher in these sectors. Imports are relatively higher in gravity II irrigation systems and in pump irrigation. The explanation for high imports in pump irrigation systems lie in importation of mini tractors while in gravity II irrigation, it lies in increased demand for consumer goods.

### Comparison of the result with the Philippines

A similar study (Ahammed and Herdt, 1963) was made for the Philippines and although the nature of the simulations were different in the two studies, some comparisons can be made. The linkages are quite substantial in both countries, but they are more important in Indonesia than in the Philippines. The reasons appear to be (1) higher land productivity in Indonesia than in the Philippines, (2) relatively less importation or conversely more domestic production in Indonesia than in the Philippines, and (3) more labor intensive production systems in both industry and agriculture in Indonesia, and (4) a more egalitarian land distribution pattern in Indonesia.

## CONCLUSIONS

Increasing food production in a modernizing agriculture has the potential for large growth inducing linkages with other sectors of the economy. These linkages arise primarily because the new food-grain technology normally requires increased purchase of current and capital inputs and, more significantly, because of increased demand for goods and services produced in other sectors of the economy. It is increased marketings of food-grains and consequent increased cash farm incomes which provide the important element in the linkages. The size of the linkages depend on the production

Table 6

**Generation of Savings and Demand for Imports Under Alternative Mechanization Strategies** *

| Subsector/Systems | Savings ('000 Rp) | Import ('000 Rp) |
|---|---|---|
| 1 | 2236.2 | 2659.7 |
| 2 | 2240.0 | 2663.1 |
| 3 | 2241.2 | 2663.8 |
| 4 | 2309.3 | 2721.4 |
| 5 | 2322.3 | 2729.3 |
| 6 | 2326.2 | 2732.4 |
| 7 | 2332.7 | 2737.1 |
| 8 | 2340.1 | 2741.1 |
| 9 | 2445.0 | 2829.3 |
| 10 | 2481.3 | 2851.4 |
| 11 | 2491.0 | 2861.7 |
| 12 | 2523.3 | 2886.5 |
| 13 | 2548.6 | 2905.2 |
| 14 | 2443.2 | 2834.4 |
| 15 | 2475.5 | 2858.2 |
| 16 | 2469.2 | 2735.6 |
| 17 | 2500.3 | 2744.6 |
| 18 | 2524.3 | 2751.3 |

* Consumption is increased in each rice subsector by an amount equal to the added production arising from a thousand hectare increase in paddy cultivation.

structure, consumption behaviour, nature of import substitution and initial distribution of income.

Because of the nature of production and consumption linkages, sound planning requires knowledge of the distribution of benefits from foodgrains technology, the consumption patterns accompanying increased incomes of various socio-economic classes, the capital-labor ratios in the industries experiencing increased demand and nature of other inhibitions (like fixity of supplies, import leakages, etc.) to expansion of these industries. Because of its sheer size, the rice sector offers particular opportunity for a net increase in employment through changes in consumption expenditures arising from substitution among alternative production patterns. Exploration of these factors suggest that consumption linkages are higher for sectors giving relatively more income to hired labor. Thus, in the case of stimulus to growth arising from increased foodgrain production, long run equity and production considerations may be highly complementary.


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# A 0-1 INTEGER PROGRAMMING ALGORITHM FOR OPTIMAL SELECTION OF MUTUALLY EXCLUSIVE MACHINERY SETS

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Oram et al (1979) have estimated the current value of expected tractor and draft equipment investments by Asian countries between 1975 and 1990 at $3.95 billion. Considerable additional investment will doubtless be made in irrigation pumps, crop-care machinery, threshers, and post-harvest equipment. Although much of this equipment can and probably will be supplied by established manufacturers in developed countries, there is growing concern about the appropriateness and foreign exchange costs of such imported machinery.

An alternative is to encourage development of an indigenous farm machinery industry based on the local artisans' workshops so prevalent in much of South and South East Asia. Given sufficient encouragement, in terms of availability of appropriate basic designs, guidance on manufacturing, and assistance with marketing, some of these small businesses should expand rapidly and provide the foundations for a viable local industry. The Farm Machinery Development Program of the International Rice Research Institute (IRRI) provides one mechanism through which this objective can be achieved.

The identification, design and dissemination of appropriate agricultural machines is a complex multidisciplinary problem requiring integration of the skills of engineers, economists and agricultural scientists. The prime roles of the economist are to provide ex ante information on the likely acceptability and impact of machinery and to assist in establishing research priorities. To be effective economists must be involved at the conceptualization stage, and continue through design, testing and final machinery release. Failure to evaluate proposals adequately will result in a waste of resources and may, at worst, severely restrict the development of a potentially major industry.

The simplest and most widely used technique by which engineers evaluate machinery is private (to the farmer) benefit-cost analysis. Fixed and variable cost estimates typically depend on standardized formulas (Kepner, Bainer and Barger 1972, Hunt 1973). Machine ownership benefits — such as timeliness, yield increases and cropping intensity increases — are more difficult to quantify. Maranan (1981) assumed an implied rental rate for preparation of own land, and hence income for the tractor activity, equal to the average custom rate. Yet a farmer would be expected to prepare his own land at the optimum time and allocate any remaining time to custom operations. This implies a higher shadow price for own-farm operations than the average custom rate. An alternative (Juarez and Duff 1977)

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is to compare costs on the basis of equivalent work by an alternative power source. For example a two-wheel tractor could be evaluated by comparison with the cost of doing an equivalent amount of work using a water buffalo. The benefit would then be the costs saved by not using the water buffalo. This technique assumes that one is able to define adequately an equivalent amount of work.

Such simple benefit-cost approaches ignore possible interactions of machinery ownership and use with the rest of the farmer's resource base and cropping pattern. Machinery acquisition usually causes large changes in factor proportions which would be expected to result in altered cropping patterns. Whole-farm planning techniques, such as mathematical programming and simulation analysis, provide a mechanism for incorporating these changes.

Donaldson (1975) developed simulation models to assess cereal seeding and harvesting considering machine performance, crop yields, and losses due to untimely operations under different weather conditions. Power requirements, machinery selection, operations scheduling and costing for a given farm plan have also been considered (Hughes and Holtman 1976) as have timeliness losses (Edwards and Boehlje 1980). Monte Carlo simulation (Donaldson and Webster 1968) offers an extremely flexible approach to simultaneous selection of machinery sets and cropping pattern, but no applications appear to have been undertaken.

Although only limited inferences can be drawn, there have been several applications of linear programming to farm planning with a fixed machinery set (e.g. McCarl et al 1977). Integer programming has been applied to machinery selection in developed countries (Colyer and Vogt 1967) as well as developing countries (Gotsch and Yusuf 1975, Danok, McCarl and White 1978). Gotsch and Yusuf formulated a model to study the implications to Pakistan of withdrawing tractor import subsidies. Whilst recognising the potential of custom and cooperative operations, they considered them insufficiently developed to include in the model. Danok, McCarl and White used an integer programming model for simultaneous machinery selection and crop planning of a state farm in Iraq. Constraints were required to ensure certain machines were only selected in combination with others and combinations were prohibited.

An alternative approach, in which machinery is grouped into sets rather than sets being selected from individual machines, was developed by Danok, McCarl and White (1980). Solutions can be obtained either by integer programming, or by solving for all feasible machinery sets using linear programming. Linear programming would be a tedious process if there were more than a few options to evaluate, but the large number of solutions would provide the basis for a more thorough analysis.

Other than for the final simplified case all of the mathematical programming procedures discussed above required the availability of an integer programming algorithm. In many developing countries neither the algorithms nor the expertise to implement them are readily available. The remainder of this paper develops an alternative procedure for obtaining an integer programming optimum through solution of a limited number of linear programming problems, the algorithm for which is more widely available. The procedure is subsequently applied to farm machinery investment problem for a typical irrigated farm in Nueva Ecija, Philippines.

**Theoretical model and solution procedure**

The integer programming problem (IP) can be stated as:

(1) $$\max z = c_1x_1 + c_2x_2$$

subject to

(2) $$A_1x_1 + A_2x_2 \leq b$$

$$\lambda x_1 = 1$$

$$x_1 = 0,1$$

and $$x_2 \geq 0$$

where z is the objective function value,

$c_1$ is $1 \times l$ vector of return or cost coefficients associated with 0-1 integer variables,

$x_1$ is a $l \times 1$ vector of mutually exclusive 0-1 variables,

$c_2$ is a $1 \times n$ vector of return or cost coefficients associated with continuous variables,

$x_2$ is a $n \times 1$ vector of continuous variables,

$A_1$ is a $m \times l$ matrix of coefficients in constraints associated with 0-1 variables,

$A_2$ is a $m \times n$ matrix of coefficients in constraints associated with continuous variables,

b is a $m \times 1$ vector of resources or right hand sides, and

$\lambda$ is a summation vector - a 1 x *l* vector containing 1 as each element

The mutual exclusivity and 0-1 conditions imposed on $x_1$ by the 0-1 restriction and the constraint $\lambda x_1 = 1$, ensure that only one element of the kth element, $x_1^k$, to be one and setting all other elements to zero the problem can be rewritten in linear programming (LP) form as:

$$(3) \quad \max \quad z(x_1^k) = c_1^k x_1^k + c_2 x_2$$

subject to

$$(4) \quad A_2 x_2 \leqslant b - A_1^k x_1^k$$

and $\quad x_2 \geqslant 0$

where $c_1^k$ is the kth element of the vector $c_1$, and
$A_1^k$ is the kth column of the matrix $A_1$.

An obvious way to solve the IP (equations 1 and 2) is to solve the LP (equations 3 and 4) sequentially for all $x_1^k$ and then select the optimal solution. While practical for relatively limited problems it becomes tedious as soon as a realistic number of integer variables are considered. Solution efficiency can be greatly improved by eliminating the requirement that all of the LP problems must be solved to locate the optimum IP solution. This is achieved as follows.

The dual of the LP problem is

$$(5) \min \quad z(x_1^k) = c_1^k x_1^k + u(b - A_1 x_1^k)$$

subject to

$$(6) \quad uA_2 \geqslant c_2$$

and $\quad u \geqslant 0$

where u is a 1 x *m* vector of dual variables associated with the vector of resource availabilities, b.

Garfinkel and Nemhauser (1972) have shown that, if the dual has an optimal solution for any $x_1^k$, a constraint on $x_1$ can be specified as

$$(7) \qquad (-c_1 + u^k A_1)\ x_1 \leq -\underline{Z} + u^k b$$

where $\underline{Z}$ is the best known value of the objective function for the LP problem and $u^k$ is the row vector of optimum values from solution of the dual problem. For those cases where the dual is unbounded, that is there is no feasible solution to the primal LP problem, $x_1^k$ is inadmissible. An optimal solution to the dual problem also provides a value for $\underline{Z}$

Since the problem has been formulated with a set of mutually exclusive integer vectors and infeasible options can be eliminated during model specification, the existence of either an infeasible or unbounded solution to the primal problem will indicate the existence of a specification error in the primal model. This may not be the case for more general models (Garfinkel and Nemhauser 1972). Solution of the primal problem will provide a lower bound on the objective function, $\underline{Z}$ and a vector of resource shadow prices, $u^k$, which may be combined with b, $c_1$ and $A_1$ to evaluate inequality 7.

Partitioning $A_1$ into *l* vectors, $a_l$, each of dimension *m* x 1, inequality 7 can be rewritten as

$$(8) \qquad \sum_{j=1}^{l} (-c_{1j} + u^k a_{1j})\ x_{1j} \leq -\underline{Z} + u^k b,$$

Since all $x_{1j}$ are 0-1 and mutually exclusive, inequality 8 can be solved for each $x_1$ by sequentially setting one variable to one and all others to zero. Those $x_{1j}$ for which the constraint is not violated are retained for future consideration.

All that remains is to determine the sequence for selecting variables for consideration. From inequality 8 it is clear that the smaller, or more negative, the value of $(-c_{1j} + u^k a_{1j})$ the less likely a $x_{1j}$ is to be eliminated. Hence the $x_{1j}$ with the smallest value is selected for the next cycle. It should however be noted that since the vector of shadow prices, $u^k$, is specific to the optimum solution of the LP with $x^k$ as the integer variable, selection of an alternative variable will likely change the shadow prices and may alter the ranking of the $x_{1j}$s. This will limit the number of options eliminated at the end of that cycle and provide a new $x_{1j}$ for consideration.

The procedure systematically generates new constraints on $x_1$ whenever a new vector of dual values, u, is generated from solution of the LP, and revises the constraints with new $\underline{Z}$ whenever an improved $\underline{Z}$ is available. Both changes can result in elimination of some of the machinery sets. The process is finite and continues until either the set of reduced constraints indicates the optimal solution or all sets have been enumerated.

A flowchart for the procedure is in Figure 1 and a brief description now follows.

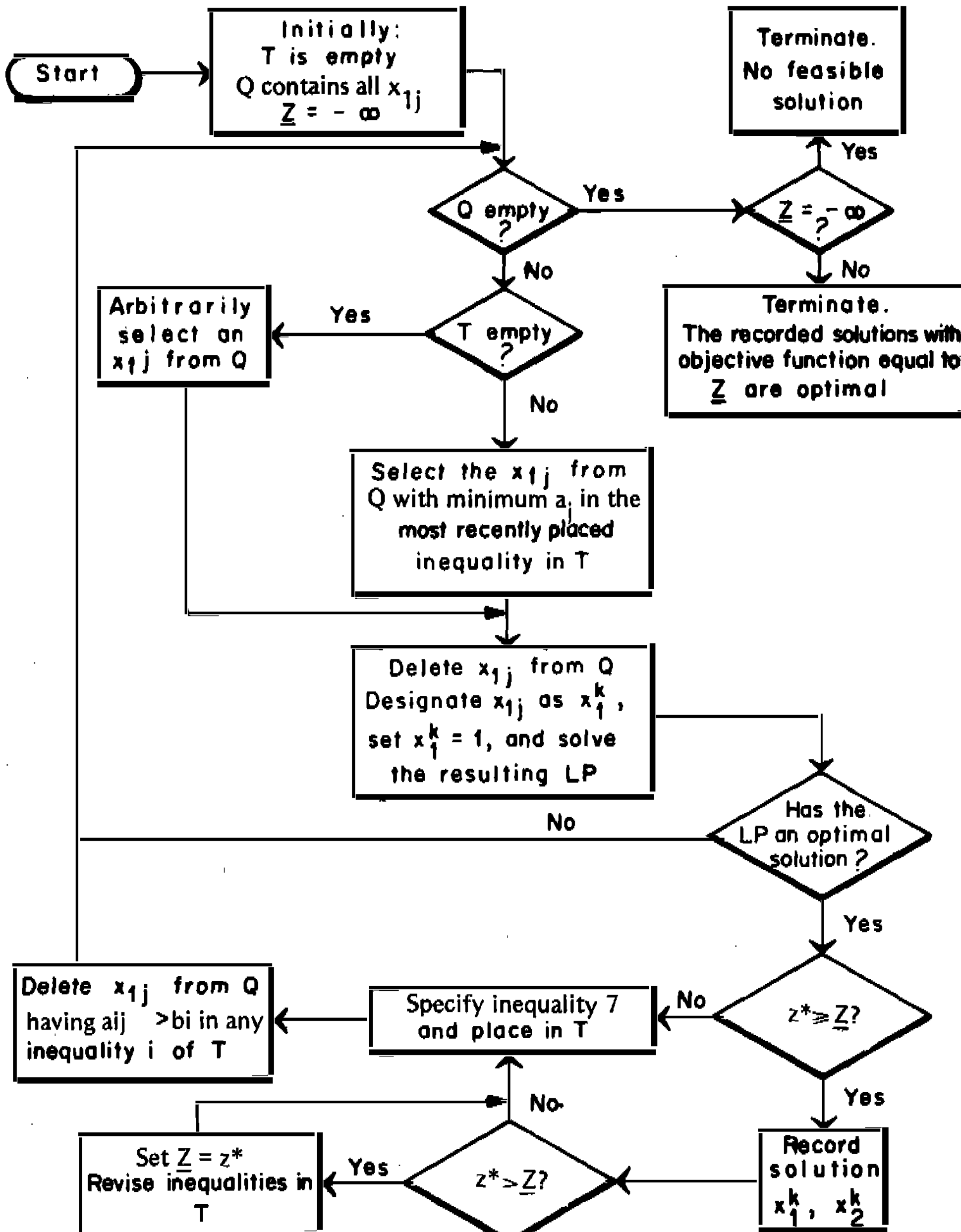


**Figure 1. Flow Diagram of the Partial Enumeration Algorithm**

Inequality 7 can be written as

$$(9) \quad \sum_{j=1}^{l} \alpha_{ij} x_{1j} - \beta_i \qquad i$$

where $\alpha = (-c_1 + u^k A_1)$ and

$\beta = -\underline{Z} + u^k b$

Step 1. Let T be the set of inequality 9 specified so far.
Initially T is empty.
Let Q be the set of $x_1$s not currently zero in the optimal solution. Initially Q contains all $x_1$.
Let $\underline{Z}$ be the best known lower bound on the objective function. Initially $\underline{Z} = \infty$.

Step 2. If Q contains at least one element go to step (3). Otherwise examine $\underline{Z}$.
If $\underline{Z} = -\infty$, there is no feasible solution. Terminate.
If $\underline{Z} \neq -\infty$, the solution most recently recorded in step (5) is optimal. Examine previously recorded solutions in step (5) for multiple optima and terminate.

Step 3. If T is empty select $x^k$ arbitrarily and go to step (4). Otherwise examine the inequality most recently placed in T at step (7). Select the $x_j$ from Q which has minimum $\alpha_j$ and designate as $x_1^k$.

Step 4. Eliminate $x_1^k$ from the set Q and solve the LP with $x_1^k = 1$. If the solution is optimal go to step (5). Otherwise go to step (2).

Step 5. If the optimal value of objective function z* (equation 3) is less than $\underline{Z}$ go to step (7). If $z^* \geq \underline{Z}$, record the solution. If $z^* > \underline{Z}$, set $\underline{Z} = z^*$ for all inequality in T.

Step 6. If T is empty go to step (7). Otherwise revise all the inequalities in T with $\underline{Z}$ and go to step (7).

Step 7. Solve inequality (9) with new $u^k$ and $\underline{Z}$, place in T and go to step (8).

Step 8. Delete all $x_{1j}$ from Q which have $\alpha_{ij}$ $\beta_i$ in any inequality i of T and go to step (2).

## AN ILLUSTRATIVE APPLICATION

The procedure was applied to a machinery selection problem for a typical irrigated rice farm in Nueva Ecija, Philippines. Data over 300 farms, collected as a part of the Consequences of Small Rice Farm Mechanization

Project (USAID contract tac-1466), together with machine specific coefficients obtained from IRRI's Agricultural Engineering Department, provided the basis for model specification.

Detailed matrix presentation is in the Appendix. The objective function consists of the net income from crop sales, machine rental, and other resource rental less the annual fixed costs of machine ownership, costs of renting in machines and costs of renting in other services. The model is defined by six constraint sets (A2 to A7 in the Appendix), upper bounds on the renting in and renting out of machinery and other resources (A8) and the usual non-negativity restrictions (A9). All field operations for crop production must be performed at the appropriate time using either the purchased machinery set or rented in machinery (A2). Total machinery use for any operation in all crops together with renting-out must not exceed the capacity of machinery available from ownership and renting in for undertaking that operation (A3). An overall constraint is imposed on all operations the power requirement for which must not exceed owned plus rented machine capacity (A4). Cash, land, water, and technical requirements of crop production must be satisfied at the correct time and transferable resources can be made available at a later time (A5). Only one machinery set can be adopted (A6), and this must be purchased as an entire unit (A7).

The model includes conventional activities as well as machinery purchase. Crop production activities are defined by crop type, variety and planting time. Machinery renting activities are included to permit either renting in or renting out of machinery. Similarly resource adjustment activities are included to permit renting in and renting out of other resources, and input supply activities to permit purchase of fertilizer, insecticide, fuel, and other inputs. Resource transfer activities are specified so that surplus resources and intermediate products from one period can be made available in subsequent periods.

Machinery purchase activities are not included explicitly in the model. Machinery is selected from the available range on the basis of a predetermined mutually exclusive set which is defined exogenously. A machinery set may consist of any, all, or none of a power source (two-wheel tractor, carabao), engine, implements (plows, harrows) and other machines (threshers, transplanters). Units included in a set must be technically compatible, and the set should be usable for the intended purposes without additional machine components. Hence it is possible to have a single machine comprising a set, in addition to that machine being in several other sets, so long as each set comprises a unique combination.

In addition to the farmer's existing power tiller, the model was specified for machinery sets to be derived from a carabao, two sizes of power tiller (PT3 and PT8), two sizes of reaper (R1 and R1.6), two sizes of thresher (TH7 and TH8), four sizes of gasoline engine (GE3, GE8, GE10 and GE16), two sizes of diesel engine (DE6 and DE8) and a transplanter. Machinery sets were formulated from these options in accordance with technical requirements, and subject to the exclusion of "unreasonable" combinations. For example power tillers could only be linked to engines of the appropriate size, and only one of the small (TH7) and large (TH8) axial flow thresher was permitted.

Figure 2 shows part of the resultant tree of feasible machinery sets. Given a ₱25,000 upper limit on investment costs, 76 potential machinery sets were identified. Solution of the LPs associated with all of the machinery sets would have been a tedious process. However, the proposed procedure required solution of only eight LP problems.

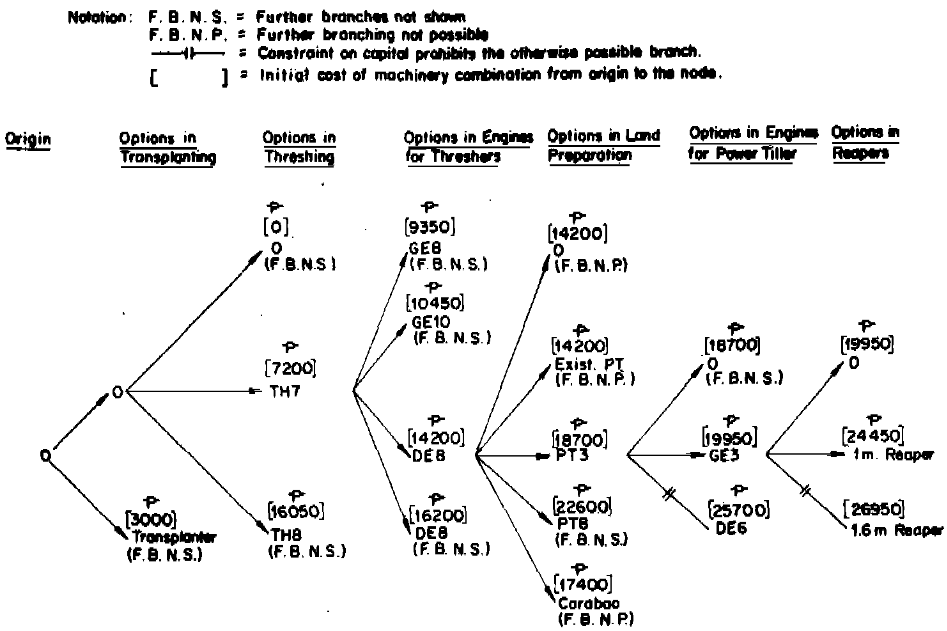


**Figure 2. A Part of Tree of Feasible Machinery Sets**

Note: Machinery units along a unique path from origin at the left to a point where further branching is impossible constitute a unique machinery set.

## Results

Iterations of the solution procedure are set out in successive columns of Table 1. Solution was initiated by solving the LP with a machinery set comprising the existing power tiller. This gave an optimal value of ₱14,857. On the basis of the lower bound, machinery set 42 (transplanter) was eliminated and machinery set 34 (TH7, GE8, PT8 and RI.6) selected for second iteration. Solution of the revised LP produced a higher objective function value, ₱25,718, and hence a revised value for $(-\underline{Z} + u^k b)$. This resulted in elimination of 25 machinery sets and selection of set number 33 for the third iteration. Again, the LP solution produced a higher objective function value requiring revision of $(-\underline{Z} + u^k b)$, and identifying machinery set 25 for the fourth iteration. Solution of iterations four through eight produced no improvement in the objective function value but resulted in elimination of all other machinery sets through revised values of the other

Table 1

Generation of Constraints for Elimination of Sub-optimal Machinery Sets

| | | COEFFICIENTS OF LEFT HAND SIDES OF INEQUALITY (7): $-c + u^k A_1$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | k = 1 | 34 | 33 | 25 | 41 | 22 | 31 | 39 |
| 1. | Existing PT | – | – | – | – | – | – | – | – |
| 2. | Carabao | 931 | – 847 | a/ | – | – | – | – | – |
| 3. | PT3 + GE3 | – 2472 | – 251 | – | – | – | – | – | – |
| 4. | PT3 + DE6 | – 6602 | + 130 | – | – | – | – | – | – |
| 5. | PT8 + GE8 | – 4606 | – 1459 | – | – | – | – | – | – |
| 6. | PT8 + GE10 | – 3798 | – 1251 | – | – | – | – | – | – |
| 7. | PT8 + DE6 | – 5922 | – 2049 | – | – | – | – | – | – |
| 8. | PT8 + DE8 | – 5727 | – 1638 | – | – | – | – | – | – |
| 9. | TH7 + GE8 | –12481 | – 6479 | – | – | – | – | – | – |
| 10. | TH7 + GE10 | –14051 | – 7150 | – | – | – | – | – | – |
| 11. | TH7 + DE6 | –11030 | – 8589 | + 1210 | – | – | – | – | – |
| 12. | TH7 + DE8 | –12436 | – 8361 | + 1755 | – | – | – | – | – |
| 13. | TH8 + GE8 | –21304 | –17171 | + 3770 | –20602 | +1358 | –20660 | + 3770 | +3770 |
| 14. | TH8 + GE10 | –22875 | –17838 | + 4129 | –22072 | +4129 | – | – | – |
| 15. | TH8 + GE16 | –30812 | –24792 | + 4292 | –29092 | +4292 | – | – | – |
| 16. | PT3 + GE3 + R1 | –45852 | + 490 | – | – | – | – | – | – |
| 17. | PT3 + DE6 + R1 | –51458 | + 1253 | – | – | – | – | – | – |
| 18. | TH7 + DE6 + PT3 | –18734 | – 9025 | – 3499 | . | – | – | – | – |
| 19. | TH7 + GE8 + PT8 | –17546 | – 8399 | – 1753 | – | – | – | – | – |
| 20. | TH7 + GE10 + PT8 | –18184 | – 9069 | – 1358 | – | – | – | – | – |
| 21. | TH7 + DE6 + PT8 | –18051 | –11740 | – 2819 | – 9836 | –6070 | – 9418 | – | – |
| 22. | TH7 + DE8 + PT8 | –19456 | –11299 | – 2256 | –11238 | –6086* | – | – | – |
| 23. | PT8 + GE8 + R1.6 | –59592 | – 9020 | – 70702 | – | – | – | – | – |
| 24. | PT8 + GE10 + R1.6 | –58785 | – 9814 | – 70449 | – | – | – | – | – |
| 25. | PT8 + DE6 + R1.6 | –60965 | –12574 | – 72014* | – | – | – | – | – |
| 26. | PT8 + DE8 + R1.6 | –60710 | –12182 | – 71507 | +3611 | – | – | – | – |
| 27. | Exist. PT + TH7 + GE8 | –18046 | – 8921 | + 2240 | – | – | – | – | – |
| 28. | Exist. PT + TH7 + GE10 | –19617 | – 9591 | + 2599 | – | – | – | – | – |
| 29. | Exist. PT + TH7 + DE6 | –16596 | –12261 | + 1210 | –10969 | – 4597 | –10033 | – | – |
| 30. | Exist. PT + TH7 + DE8 | –18001 | –11820 | + 1759 | –12353 | – 4613 | – 8681 | – | – |
| 31. | Exist. PT + TH8 + GE8 | –26870 | –19612 | + 3710 | –20602 | – 1774 | –22078* | – | |
| 32. | Exist. PT + TH7 + GE10 | –28440 | –20279 | + 4129 | –22043 | + 1415 | –22007 | +4129 | – |
| 33. | Exist. PT + TH8 + GE16 | –29177 | –27233* | – | – | – | – | – | – |
| 34. | TH7 + GE8 + PT8 + R16 | –72533* b/ | – | – | – | – | – | – | – |
| 35. | Carabao + TH7 + GE8 | –13411 | – 7782 | + 1309 | – | – | – | – | – |
| 36. | Carabao + TH7 + GE10 | –14982 | – 8452 | + 1668 | – | – | – | – | – |
| 37. | Carabao + TH7 + DE6 | –11963 | – 9892 | + 279 | – | – | – | – | – |
| 38. | Carabao + TH8 + DE8 | –13367 | – 9663 | + 828 | – | – | – | – | – |
| 39. | Carabao + TH8 + GE8 | –22235 | –18474 | + 2839 | –20083 | + 2831 | – 21919 | +2831* | – |
| 40. | Carabao + TH8 + GE10 | –23805 | –19149 | + 3198 | –21524 | + 3190 | – 21848 | +3190* | – |
| 41. | Carabao + TH8 + GE16 | –31742 | –26095 | + 3361 | –29174* | – | – | – | – |
| 42. | Transplanter | + 581 | – | – | – | – | – | – | – |
| 43. | Transplanter + Set 1 | – 4985 | – 1860 | – | – | – | – | – | – |
| 44. | Transplanter + Set 2 | – 350 | – 266 | – | – | – | – | – | – |
| 45. | Transplanter + Set 3 | – 1891 | + 330 | – | – | – | – | – | – |
| 46. | Transplanter + Set 4 | – 6021 | + 711 | – | – | – | – | – | – |
| 47. | Transplanter + Set 5 | – 4025 | – 878 | – | – | – | – | – | – |
| 48. | Transplanter + Set 6 | – 3217 | – 643 | – | – | – | – | – | – |
| 49. | Transplanter + Set 7 | – 5341 | – 1468 | – | – | – | – | – | – |
| 50. | Transplanter + Set 8 | – 5146 | – 1057 | – | – | – | – | – | – |
| 51. | Transplanter + Set 9 | –11900 | – 5859 | – | – | – | – | – | – |
| 52. | Transplanter + Set 10 | –13470 | – 6569 | – | – | – | – | – | – |
| 53. | Transplanter + Set 11 | – 10449 | – 8008 | – | – | – | – | – | – |
| 54. | Transplanter + Set 12 | – 11855 | – 7780 | + 2336 | – | – | – | – | – |
| 55. | Transplanter + Set 13 | – 20723 | –16590 | + 4351 | – | – | – | – | – |
| 56. | Transplanter + Set 14 | – 22294 | –17257 | + 4710 | – | – | – | – | – |
| 57. | Transplanter + Set 15 | – 30231 | –24211 | + 4873 | – | – | – | – | – |
| 58. | Transplanter + Set 16 | – 45271 | + 1071 | – | – | – | – | – | – |
| 59. | Transplanter + Set 17 | – 50877 | + 1834 | – | – | – | – | – | – |
| 60. | Transplanter + Set 18 | – 18153 | – 8444 | – 2918 | – | – | – | – | – |
| 61. | Transplanter + Set 19 | – 16965 | – 7818 | – 1172 | – | – | – | – | – |
| 62. | Transplanter + Set 20 | – 17601 | – 8488 | – 777 | – | – | – | – | – |
| 63. | Transplanter + Set 23 | – 59011 | – 8439 | – 70121 | – | – | – | – | – |
| 64. | Transplanter + Set 24 | – 58204 | – 9233 | – 69868 | – | – | – | – | – |
| 65. | Transplanter + Set 27 | – 17465 | – 8339 | + 2821 | – | – | – | – | – |
| 66. | Transplanter + Set 28 | – 19036 | – 9010 | + 3180 | – | – | – | – | – |
| 67. | Transplanter + Set 29 | – 16015 | –11680 | + 1791 | –10388 | – 4016 | – 9452 | – | – |
| 68. | Transplanter + Set 30 | – 17420 | –11239 | + 2340 | –11772 | – 4032 | – 8100 | – | – |
| 69. | Transplanter + Set 31 | – 26289 | –19031 | + 4351 | – | – | – | – | – |
| 70. | Transplanter + Set 32 | – 27859 | –19698 | + 4710 | – | – | – | – | – |
| 71. | Transplanter + Set 33 | – 28596 | –26652 | 4873 | – | – | – | – | – |
| 72. | Transplanter + Set 36 | – 12830 | – 7201 | – | – | – | – | – | – |
| 73. | Transplanter + Set 37 | – 14401 | – 7871 | 2249 | – | – | – | – | – |
| 74. | Transplanter + Set 38 | – 11382 | – 9311 | 860 | – | – | – | – | – |
| 75. | Transplanter + Set 39 | –12786 | – 9082 | 1409 | – | – | – | – | – |
| 76. | Transplanter + Set 40 | – 12654 | –17893 | 3420 | –19502 | +3412 | – | – | – |
| | | ∧ | ∧ | ∧ | ∧ | ∧ | ∧ | ∧ | ∧ |
| | $-\underline{Z}$ | –14857 | –25718 | 29380 | –29380 | –29380 | –29380 | 29380 | –29380 |
| | $u^k b$ = | + 14857 | – 7238 | 4292 | –7900 | 3204 | 12144 | + 3992 | 2904 |
| Right | 1: $-\underline{Z}_1 + u^k b$ = | 0 | – | – | – | – | – | – | – |
| hand | 2: $-\underline{Z}_{34} + u^k b$ = | – 10861 | +18480 | – | – | – | – | – | |
| side c/ | 3: $-\underline{Z}_{33} + u^k b$ = | – 14523 | –10900 | + 33672 | +21480 | +32584 | +17236 | 33372 | 32284 |

a/ – Indicate the machinery set has been either enumerated or eliminated.
b/ * indicate machinery set selected for next iteration
c/RHS of constraint under k = 1 revised twice using $-\underline{Z}$ generated by k = 34 and k = 33. For k = 34, $-\underline{Z}$ was revised once. No subsequent improvement on $-\underline{Z}$ were generated.

vectors. The optimum solution was defined as the LP solution of the problem with a machinery set consisting of the existing power tiller, TH8 and GE16 (set number 33). This solution, which was identified at the third iteration, yielded a gross margin of P29, 380.

The optimal machinery set may serve as a good starting point for solving further problems which differ only in a few parameters from the initial problem, such as in the case of parametric analysis. Although it may provide a value of $-\underline{Z} + u^k b$ which will eliminate many of the sub-optimal machinery sets several further iterations will probably be required to locate the optimum solution.

## CONCLUSIONS

Evaluation of alternative mechanization options is one of the most important roles of an economist working collaboratively with agricultural engineers. The provision of timely and comprehensive analyses of the feasibility and ranking of alternative research strategies can provide guidance in research resource allocation. One of the major areas for this research is the evaluation of machines from the farmer's perspective.

Although considerable work has been undertaken in evaluating machinery investment within a whole-farm framework, the IP algorithms and computer hardware required are rarely available in developing countries. This prompted reformulation of the machinery selection problem as a 0-1 IP model with mutually exclusive integer variables. A solution procedure was developed which used the more readily available LP algorithm and allowed elimination of many of the potential machinery sets without solving the related LPs.

Application of the procedure to a machinery selection problem for a typical small, irrigated rice farm in Nueva Ecija, Philippines demonstrated its efficiency. As currently formulated, problems are evaluated by first solving the LP problem using a conventional package, then manually eliminating suboptimal machinery sets and selecting the one for the next trial. However, it would be relatively easy to combine these stages in an iterative computer algorithm which would facilitate problem solution by using the optimal solution for one iteration as the starting point for the next.

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## APPENDIX

The farm matrix may be represented as:

Maximize

(A1) $$Z = -\sum_m C_m X_m + k\ t\ q\sum_{k,t}\sum Q_{k,t} - \sum_f\sum_h\sum_p s_{f,h,p} S_{f,h,p}$$

$$+ \sum_f\sum_m\sum_p t_{f,m,p} T_{f,m,p} - \sum_r\sum_p w_{r,p} W_{r,p} + \sum_r\sum_p y_{r,p} Y_{r,p}$$

Subject to

(A2) $$-\sum_m e_{f,m,p} L_{f,m,p} - \sum_h i_{f,h,p} S_{f,h,p}$$

$$+ \sum_k\sum_t a_{f,k,p,t} Q_{k,t} \leq 0$$

for all valid f, p

(A3) $$-\sum_m d_{f,m,p} X_m + \sum_m L_{f,m,p} + \sum_m T_{f,m,p} \leq 0$$

for all valid f, pp

(A4) $$-\sum_f d_{f,m,p}\ X_m + \sum_f L_{f,m,p} + \sum_f T_{f,m,p} \leq 0$$

for all valid m, p

(A5) $$-B_{r,p} - W_{r,p} + Y_{r,p} + \sum_f\sum_m g_{r,f,m,p} L_{f,m,p}$$

$$+ \sum_k\sum_t h_{r,p,k,t,} Q_{k,t} + B_{r,p+1} \leq b_{r,p}$$

for all valid r, p

(A6) $$\sum_m X_m \leq 1$$

(A7) $$X_m = 0, 1 \text{ for all } m$$

(A8) all S, T, W and Y are bounded above and

(A9) all L, Q, S, T, W, Y, B $\geq 0$

where:

$Z$ is the total net return

$C_m$ is the fixed cost of machinery set m for the planning per

$X_m$ is a 0–1 variable for ownership of machinery set m,

$q_{k,t}$ is net revenue per hectare from crop k planted at time t,

$Q_{k,t}$ is hectares of crop k planted at time t,

$s_{f,h,p}$ is cost per hour of operation f using hired machinery set h in period p,

$S_{f,h,p}$ is hours of hired machinery set h using operation f in period p,

$t_{f,m,p}$ is rental income per hour for operation f using machinery set m in period p,

$T_{f,m,p}$ is hours of renting out for operation f of machinery m in period p,

$w_{r,p}$ is cost per unit of renting in or purchasing resource/input r in period p,

$W_{r,p}$ is units resource/input r rented in or purchased in period p,

$y_{r,p}$ is revenue per unit from renting out or selling resource r in period p,

$Y_{r,p}$ is units of resource r rented out or sold in period p,

$e_{f,m,p}$ is capacity for field operation f in hectares per hour of purchased machinery set m in period p,

$L_{f,m,p}$ is hours of own farm operation f with machinery set m in period p,

$i_{f,h,p}$ is capacity for field operation f in hectares per hour of rented machinery set h in period p,

$a_{f,k,p,t}$ is the number of passes of operation f required in period p for crop k, planted at time t,

$d_{f,m,p}$ is the maximum number of hours of operations f provided by machinery set m in period p,

$B_{r,p}$ is the number of units of resource/input r transfered to period p from previous period,

$b_{r,p}$ is the number of units of resource/input r available in period p from farmer's endowment,

$g_{r,f,m,p}$ is the number of units of resource/input r required per hour of operation f with machinery set m in period p,

$h_{r,p,k,t}$ is the number of units of resource/input r required per hectare in period p for crop k planted at time t.

ACTIVITIES

| CONSTRAINT | Machinery Set Ownership | Borrow Long Term Capital | Borrow Cash for Season | Land Preparation (by Machinery Set) | Service Renting Out (by Machinery Set and Operation) | Service Renting In (by Machinery Set and Operation) | Crop Establishment (by Method) | Manual Labour Hiring (by Operation) | Operator Labour Hiring (by Operation) | Input Purchasing (by Period) | Crop Reaping (by Machinery Set) | Threshing (by Machinery Set) | Payment in Kind | Grain for Family | Grain Sale | RIGHT HAND SIDE |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Objective function | – | – | – | | + | – | | – | – | – | | | | | + | |
| Machinery ownership | + | | | | | | | | | | | | | | | ≤1 |
| Land preparation capacity in hectares | – | | | + | + | – | | | | | | | | | | ≤0 |
| Crop establishment capacity in hectares | – | | | | | | + | | | | | | | | | ≤0 |
| Reaping capacity in hectares | – | | | | | – | | | | | + | | | | | ≤0 |
| Threshing capacity in hectare | – | | | | + | – | | | | | | + | | | | ≤0 |
| Manual labour by period | | | | + | + | | + | – | | | + | + | | | | ≤+ |
| Operator labour by period | | | | + | + | | + | | | | + | + | | | | ≤+ |
| Long term loan | + | – | | | | | | | | | | | | | | ≤0 |
| Cash (by period) | | | – | + | – | + | + | + | + | + | + | + | | | – | ≤+ |
| Land | | | | + | | | | | | | | | | | | ≤+ |
| Land for crop establishment | | | | – | | | + | | | | | | | | | ≤0 |
| Inputs application (by period) | | | | + | | | + | | | – | | | | | | ≤0 |
| Crop for reaping | | | | | | | – | | | | + | | | | | ≤0 |
| Crop for threshing | | | | | | | | | | | – | + | | | | ≤0 |
| Yield | | | | | | | | | | | | – | + | + | + | ≤0 |

Figure A. Schematic of Model Matrix