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LINEAR PROGRAMMING AS A TOOL FOR AGRICULTURAL SECTOR ANALYSIS†

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As sector programming models have increased in number, they have also increased, individually, in size and complexity. This increased sophistication has presented to researchers well-defined and difficult choices, the resolution of which usually involves compromise of either model generality or theoretical rigor. This paper discusses problems typical of those encountered in construction of large-scale programming models, and presents an overview of the goals of such models and the uses to which they have been applied.

Large-scale programming models of entire economic sectors have become commonplace. This trend towards increased sophistication has not led to more versatile general-purpose policy-testing models, but rather has resulted in specific purpose models with rigorously defined structural relationships and a limited capacity for further extensions and uses beyond those originally planned.

The purpose of this paper is to discuss, in broad terms, problems typical of those which have led to increased specialization in programming models, and to illustrate the goals and uses of such models. It is hoped that in the process, some perspective on the capabilities, limitations and state-of-the-art of this particular type of model will be provided.

No attempt is made here at a comparison of models or at an exhaustive review of models world-wide. Rather, four specific models (Aggregative Programming Model of Australian Agriculture—APMAA—at the University of New England; Centre for Agricultural and Rural Development models—CARD—at Iowa State University; the National Model—U.S. Department of Agriculture; and CHAC— a model of Mexican agriculture by the World Bank) are discussed in order to illustrate the range of problems, methodology and goals existent in such efforts.

A brief description, with hindsight, of the development of APMAA is presented below with particular attention to conflicts (typical of such models) between aims and means which usually require compromises of one type or another. This is followed by discussion of the other three

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models (listed above) with emphasis on the purposes, general orientation, and uses of each. The paper then concludes with an attempt to summarize the possibilities and problems involved in construction of an 'ideal' model.

1 AN AGGREGATIVE PROGRAMMING MODEL OF AUSTRALIAN AGRICULTURE (APMAA)

The establishment of a research project for development of an Aggregative Programming Model of Australian Agriculture constituted an ambitious first effort of large-scale sector modelling in Australia.

A flow chart from the early planning stages of APMAA is presented in Figure 1. The basic unit treated was to be the representative farm (RF), a hypothetical construct deemed to reflect the structure of a group of 300 to 400 assumed homogenous farms. It was hoped that differentiation of RFs by region, size, and type would give credence to the homogeneity assumption. Input for the construction of RF matrices included price and yield expectations, resource levels, input/output coefficients and behavioural planning rules. A mechanism to reflect farmer behaviour (mainly with respect to risk) was included in each matrix to counter the oft-expressed dissatisfaction with strictly profit-maximizing LP models. The time horizon of each LP was to be one year, and individual RF LP matrices were to be run independently. This assumption of independent RFs was justified by the export orientation of Australian agriculture and by the concentration of the Australian populace on the coast line. Farm inputs and outputs necessarily flow to and from the coast, whether they are imported (exported) or produced (consumed) domestically.

An LP subroutine would produce a farm plan for each RF. The expected outcome of the plan would then be altered by a weather simulator to produce an 'actual' result. This final result would then be scaled and aggregated to the desired levels. The entire system was to be recursive with inter-year adjustments for each RF.

The APMAA modelling effort was overly ambitious in that it attempted to incorporate four features (farmer behaviour, extreme disaggregation, weather uncertainty, and recursiveness) into a single model. While each of these features has been successfully employed one-at-a-time in models elsewhere, APMAA represented the first attempt to incorporate the lot in a single large-scale model. As the project did not have unlimited funds, the task proved to be too great and modifications were required. Some of the problems encountered by APMAA, many of which are typical to such models, are discussed below.

1.1 BEHAVIOURAL SECTOR

Considerable effort was directed to experimentation with the behavioural sector of the RF LP matrix. There are a number of methods for constraining an LP matrix to reflect non-profit-maximizing objectives.

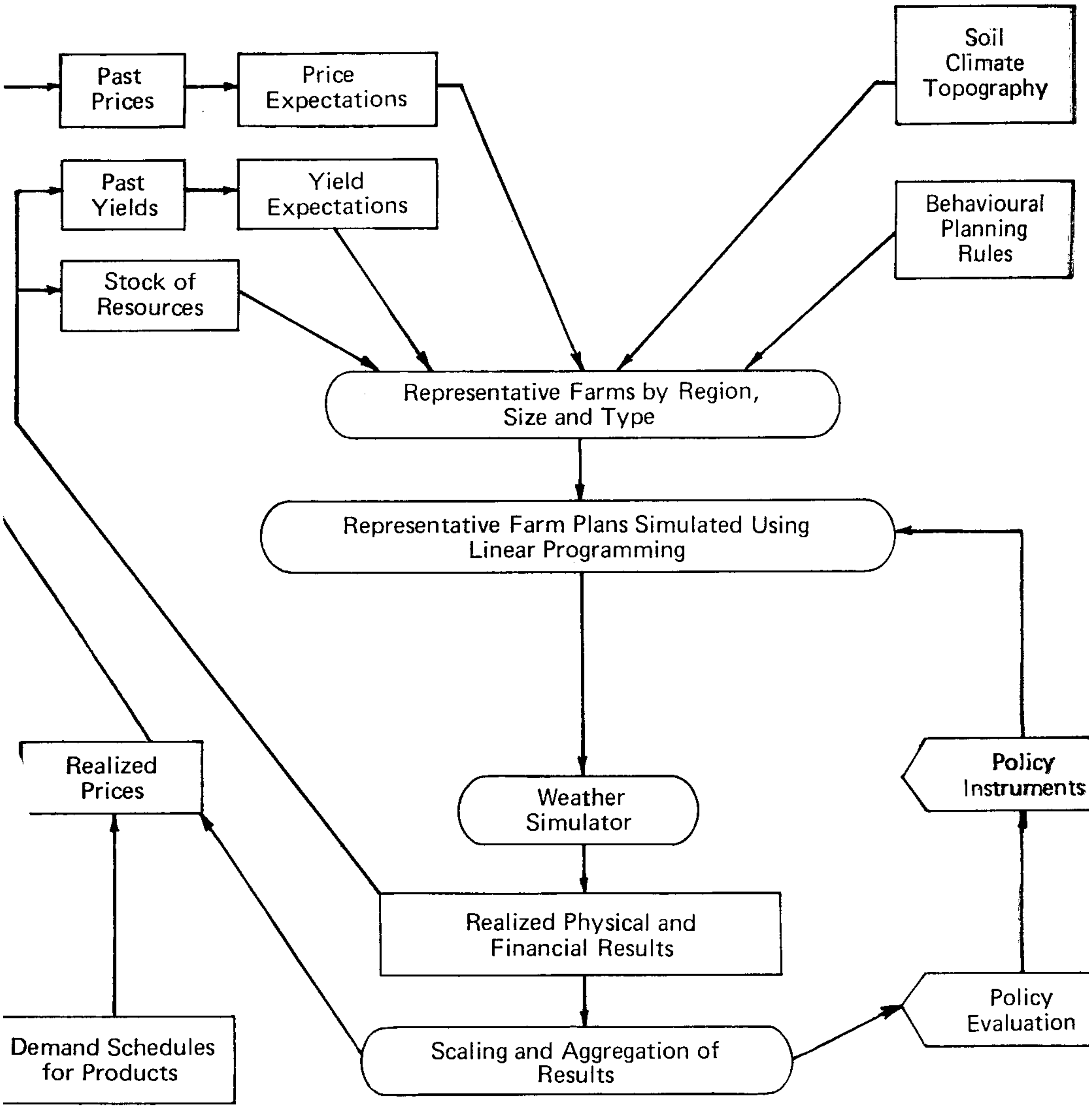

FIGURE 1. *Flow Diagram of the Structure of APMAA*

Three such methods experimented with include flexibility constraints, minimization of total absolute deviation (MOTAD) and focus-loss constrained programming (FLCP)[1].

Flexibility constraints consist of upper and lower bounds allowed during a single time period for each of the relevant activities in the LP matrix. They are thus a catch-all for any deviation from a profit-maximizing objective function. Though simple in concept, flexibility constraints can become quite complicated in specification because of the large number of items being reflected (i.e. risk aversion, farmer inertia, incomplete information, etc.). Historical information is usually utilized in specifying the constraints but methodology employed in the use of the historical data can vary considerably [11] [15] [16].

APMAA has made only limited use of flexibility constraints (and with only limited success), mainly due to lack of reliable farm-level data. Discussion of a large programming endeavour which made extensive use of flexibility constraints (U.S.D.A.'s National Model) is included elsewhere in this paper.

Quadratic programming (QP) as developed by Markowitz [10] offers a means of incorporating risk behaviour by minimizing variance (V) of gross margins for associated levels of expected income (E). This forms an E-V efficient boundary for all feasible farm plans. However, computer algorithm requirements have remained somewhat restrictive to widespread usage of the method. An alternative to quadratic programming proposed by Hazell [6] assumes that gross margins for the planning year will be drawn from the historical pattern of yearly gross margin outcomes. Obtaining the planned year results then involves minimization of total absolute deviation (MOTAD), as opposed to minimization of variance by QP. MOTAD generates an efficient E-A boundary of all feasible farm plans.

Consideration of risk can also be incorporated via focus-loss-constrained-programming as developed by Boussard [2]. This assumes that a decision-maker maximized expected income subject to some specified probability of obtaining some minimum level of income (MINI). Thus FLCP generates an efficient E-MINI boundary of all feasible farm plans.

Once an efficient boundary (however defined) is obtained, some means of assessing the risk attitudes of the decision-maker is required in order to obtain a unique solution; i.e. an E-V (or E-A or E-MINI) preference function is required.

MOTAD has been used in a number of farm-level studies with some degree of success in helping individual farmers plan for the future. Similarly Boussard [1] reports that FLCP has been shown to closely trace farmer behaviour over a period of years. This would suggest that

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[1] This paper assumes the reader to be familiar with these methods, since detailed explanations of each would be lengthy. For further reading on the subject, see [16], [6] and [2].

either MOTAD or FLCP might be useful in an aggregative programming model in which the basic unit is a representative farm. However, several problems arise in this context.

The assumption of homogeneity of the farms represented by a single RF is often difficult to justify in physical terms. Use of behavioural criteria means either that the behaviour of farmers must be taken into account when subdividing total farms or that an additional assumption is required, such being that farms with similar physical resource situations behave similarly. Either choice is hazard laden.

The APMAA team devoted considerable resources to incorporation of FLCP into the model. The general conclusion which evolved was that a tradeoff exists between (1) a theoretically appealing formulation which was difficult, at best, to quantify, and (2) a less theoretically rigorous formulation based on a combination of local expertise and judgement. The former alternative would require extensive data input from farm level studies (not presently available) while the latter would require assistance from a large number of regional economists with experience in evaluating individual farm behaviour (also presently non-existent). Thus incorporation of behaviour in APMAA remains an unresolved issue.

This trade-off is typical of the type of problems encountered in attempting to build a model which adequately reflects the real-world situation at both the farm and aggregate levels. Large, complex LP models that have been constructed for individual farms require much cooperation between the one farmer and the one model-builder. To construct many such models within an aggregative programming framework requires either unrealistically high manpower inputs or the inclusion of simplifying, but also compromising assumptions[2].

1.2 WEATHER SIMULATOR

Farmer plans are generated in APMAA by a linear programming subroutine based on expected yields. The outcome of the farmer's plan is highly dependent on weather conditions. Because Australian agriculture is characterized by a high degree of weather uncertainty, APMAA contains a weather simulator which generates a "realized" yield which, in turn, determines the "outcome" of the farm plan. The weather simulator, which is based on data covering 30 years, consists of two parts; a rainfall generator and a system of equations which generate yields as a function of rainfall.

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[2] One alternative is the use of extension farm-management LP models as an input to aggregative models. There are several U.S. institutions which offer advice to individual farmers via LP simulation of their individual operations. Such LP models can then form input to larger models. Two problems arise: (1) the farmer who uses this service (and usually pays for it) is not likely to be typical of farmers in the area; and (2) there exists, at present, little evidence that farmers using such services actually follow the 'optimal' paths generated for their farms. Nonetheless, this approach to input data for aggregative models appears certain to receive increased attention in the near future.

Output from the rainfall generator consists of monthly rainfall distributions for each region. The generator takes into account rainfall correlations between regions using multivariate analysis techniques.

The yield generator output consists of regional yield distributions (by commodity) conditional on rainfall. Multivariate techniques are used to adjust yield distributions to take into account residual correlations between products.

Two points should be noted here: (1) Data input for a weather simulator can add significantly to total model data requirements, again especially in the case of regional models; and (2) use of a weather simulator is not straight-forward, in that a drought situation (once defined) may differ amongst regions and a non-ambiguous definition of a national "drought situation" is difficult, at best. Thus users wishing to study "drought policy" must usually resort to many simulations which, of course, add to the complexity of computer soft-ware employed, to the cost of operating the model, and to the time required for problem turnaround.

1.3 RECURSIVE ASPECTS

The original formulation of APMAA was designed to produce yearly results for a specified time period through a recursive mechanism. This has been largely abandoned due to difficulties in formulating realistic adjustment rates (a problem which is closely related to farmer behaviour discussed above) and in incorporation of appropriate adjustment mechanisms within the model. In structuring farm adjustment rates, both the time span and external aspects must be considered. While a farmer might be willing (and able) to expand his beef cow herd by (say) 25 per cent in a single year, he might be neither willing nor able to expand the herd by 100 per cent in a four year period. Similarly, one farmer might desire to expand beef cow numbers by 25 per cent, but if all farmers in an area desire to do so, aggregate supply of beef cows may be inadequate for the expansion. In each of these cases, the aggregate (in time or space) adjustment rate is not simply the summation of disaggregate rates. Assuming that all relevant parameters can be specified, incorporation of longrun, shortrun and external effects on adjustment rates into the model poses serious methodological problems. Simplifying assumptions and an accompanying loss of realism or versatility is required.

1.4 DISAGGREGATION

Representative farms in APMAA are classified by size, by type and by region. Three *size categories* are specified relative to other farms of the same type in the same region. A given region may contain as many as six *farm types;* beef, sheep, dairy, cereal grain, sheep-grain, and multi-purpose. Representative farms are typed by the predominant activities which exist on the farm.

Regions are determined according to the Australian Bureau of Statistics data-gathering classifications. For the State of New South Wales, there are 125 representative farms distributed amongst 14 regions. For Australia as a whole, there will be an estimated 524 representative farms. On average, each representative farm represents some 400 actual farms. This level of disaggregation allows the user to relate a specific policy to a relatively small, locationally specific group of producers. Further the effects of a given policy may be viewed in relationship to the degree of weather uncertainty which exists in each region.

While data requirements for this degree of disaggregation have been somewhat restrictive, it is the *quality* of data which has been most bothersome. Reliable estimates of items such as labour requirements and pasture feed production have proven elusive at both the farm level and regional levels. Again, data problems are common to most, if not all, large-scale models.

Data gathering agencies have, in recent years, compiled ever larger quantities of data, often in highly disaggregated form. However, many problems exist in utilization of such data in modelling endeavours. Model-builders must either structure models to fit available data-gathering definitions and classification procedures, or adjust available data to fit model needs. While it may be possible in some cases for compilers of data and model-builders to work together, such may negate the value of data collected in past years. Too, if there exists more than one modelling group requesting special services from data gathering agencies, conflicts inevitably occur.

1.4 COMPUTER SOFTWARE

Computer algorithms associated with large-scale models occupy a determining position relative to efficiency and turnaround time. Whereas small models may rely on a single algorithm, larger models usually require several, involving editing of data tapes, extraction of data from data banks for use in a single run, producing solutions, simulation of deviations from the basic solution, aggregation, and output manipulation and printout. In addition, some models may also encompass multi-level modelling, in which case iteration between levels may be required. Utilization of several algorithms to produce a single "policy run" is time consuming and may seem inefficient. It is possible to combine several of these single function algorithms into one algorithm with many options. Such requires that all options which may be needed "someday" be anticipated at an early stage of development. Even if foresight is adequate, the resulting generalized algorithm will be complex and will have many features which are likely never to be used.

"Canned programs" for accomplishing many of these tasks are available. However, such programs usually require alteration to accommodate features specific to the model being constructed, or, alternatively, the model must be restricted to the capabilities of the algorithm.

It has been the experience of the APMAA team that it is more efficient, in the long run, to write computer algorithms from scratch, use a number of single function algorithms and adapt these to specific policy runs. However, it should be emphasized that in decisions at all levels of model-building, there are few hard rules or "right" choices to make.

1.5 SUMMARY

This sector on the developmental problems of APMAA has illustrated some decisions typical of those faced by all modelling efforts. There are many other specific aspects of aggregative programming model methodology which could be listed, such as methods of reducing aggregation bias, estimation of flexibility constraints, incorporation of recursive mechanisms, input data definitions, multi-year decisionmaking, etc. As each aspect of the model is structured and defined, the model becomes more restricted in generality and applicability. This leads (or should lead) to close scrutiny (at an early stage of development) of what can be expected, in terms of quantitative estimates of policy options, from a single model.

Discussion of three other large-scale programming models is presented below with emphasis on the specific orientation and type of policy questions each attempts to analyse.

2 CENTRE FOR AGRICULTURAL AND RURAL DEVELOPMENT (CARD)

A considerable number of models of U.S. agriculture have been developed at CARD over the past few years. While quadratic programming and econometric models have been developed in more recent years, most CARD models utilize linear programming, and discussion here is limited to these LP models. The models have examined a wide range of policy questions and have absorbed large quantities of manpower and money. Basic to all the general modelling efforts at CARD is an extensive U.S. data bank. This data bank contains information on producing regions, comsuming regions and transportation costs between regions. Producing regions are delineated by dominant soil type and management practices. Basic producing regions may be aggregated or subdivided (along county lines), depending on the policy question addressed and the commodities involved. Thus the number of producing regions utilized varies among studies from fewer than 10 to more than 200. Similarly the number of consuming regions varies from fewer than 10 to more than 70, depending on the commodities involved. Each consuming region has a hub (a centre of transportation or commerce) that represents the location of its demand.

While CARD LP models have tended to increase in size (more producing and consuming regions) and scope (treatment of an increasingly broad range of problems), basic model characteristics have remained rather constant. Point estimates of demand are satisfied in the least-cost manner, no account is taken of the effect of production variability on farmer behaviour, and results are considered strictly normative.

The most impressive aspects of CARD models are the sheer physical size of the models (suggested by the large number of producing and consuming regions) and the methods utilized to incorporate various policy issues. While much effort was required for initial specification of the extensive data bank, efficient and extensive computing software has allowed CARD to exploit the data extensively.

Interesting examples of policy analysis include recent models which simulate regulations regarding soil-loss and pollution of waterways [12]. Producing regions were aggregated to major watershed systems. Cultural practices were then limited to reflect various levels of recommended soil-loss standards formulated by the U.S. Soil Conservation Service. Levels, distributions and costs of production of major commodities, and the effects of soil erosion on waterways were then generated under each variation of soil-loss standards.

In formulating a variation of the soil-loss study, use was made of the fact that agricultural chemicals tend to bond, either to soil particles or to water. Thus the effects of restrictions on chemical use by farmers was simulated [19]. Proposed regulation of feedlot runoff (into watershed systems) was also simulated in a similar manner[3].

Two recent extensions to the basic CARD LP analysis have been the investigation of the effects of weather on the outcome of farmer plans, and the use of multipliers from input-output models to extend the results (related to agriculture) of models to analysis of the entire rural sector [14] [18]. However these studies appear to be deviations from CARD modelling techniques rather than new directions.

2.1 SUMMARY

CARD models have evolved over many years, starting from very simple formulations. The basic structure of the models has remained fairly consistent and unsophisticated. The CARD extensive data bank is not kept closely current, but is exploited through many model uses (all normative in nature).

CARD models have considerable utility in analysis of problems which require normative solutions, broad geographic and commodity coverage, and consequently, large data inputs. However CARD's potential for analysing short-run problems with quick turnaround time is highly limited due to lack of sophistication, timeliness and a current data bank. Thus the factor which gives CARD models their utility—the extensive data bank—is also the factor which prohibits versatility, timeliness and currency.

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[3] Other examples of the many models developed at CARD are listed in the references to this paper [7], [8], [9] and [12].

3 NATIONAL MODEL (U.S.D.A.)

In the National Model [17], the U.S. was divided into seven geographic regions, each of which included several (a total of 47) production areas. Within each production area were one or more resource situations (a total of 95) delineated by soil type, irrigation water availability and farm size. A separate LP submodel was constructed for each resource situation. The model was intended to be a simulation tool for analysing the effects of various U.S. farm programs.

It was originally intended to use many physical constraints in each LP submodel, such as cropland, labour, capital, irrigation water and livestock facilities. Flexibility constraints were to be used as supplementary bounds to reflect forces not represented by physical restraints. Labour and capital constraints were eventually dropped from the model due to insufficient data resources. Livestock requirements were found to be non-constraining and thus cropland became the only effective physical bound. Flexibility constraints then became determining factors in the model.

The National Model proved useful to policy analysts in spite of its simplicity, but this was due mainly to the unique situation which existed at the time. USDA assigned regional economists in various parts of the U.S. to provide local expertise for model input. Much effort was devoted to specification of the flexibility constraints. There existed, at the time, a formidable farm program which affected major crops treated by the National Model, and a history of farmer behaviour relative to past program specifications *on an individual farm basis*. Proposed changes to farm programs involved not major revisions, but changes in a few key parameters, leaving the basic structure of the programs intact. Regional economists found that, after preparing the data for a particular simulation run in a particular resource situation, the results were predictable without resorting to the LP solution. However, because of the large number of resource situations involved and the existing LP-simulation model with its aggregating features, the easiest way of processing and analysing the results was to use the LP model.

Thus, to summarise the National Model, a programming framework was useful in this instance as a device for manipulation and summarization of a large number of independently foreseeable results. Lack of sufficient data and of adequate understanding of on-farm structural relationships resulted in loss of sophistication and a high reliance on flexibility constraints. Flexibility constraints were useful because of the limited changes in government farm programs during the study period and the existence of extensive individual farm records upon which to rely for data input.

The National Model was begun in 1963. By 1968, the basic model was complete and tested and a major revision undertaken. The aggregative programming approach was abandoned (for purposes of short-run projection) in 1973. Major reasons for seeking other simulation methods included a slow turnaround time for the National Model and the emergence of significant structural changes in U.S. farm programs which made estimation of flexibility constraints more difficult.

4 CHAC

CHAC (after the Mayan rain god), is an agricultural sector programming model of Mexican agriculture [4]. The aims of CHAC differ significantly from APMAA, the National Model, and CARD models in that the links between the agriculture sector and macro economic factors are of prime importance. Linkages with DINAMICO, a model of the entire Mexican economy, allow CHAC model-results to be reflected at the national level. Results under both perfect competition and monopoly are generated, in terms of many variables including employment, sector output, income levels, the regional distribution of income, price levels, exports and imports, and use level of other input factors besides labour.

The model includes production of thirty-three major short-cycle crops produced in twenty geographical regions. Most major inputs are priced at market-observed rates, and supplies are assumed perfectly elastic. Some production inputs are specified seasonally or fortnightly. Commodity demand functions (as opposed to point estimates of demand) are incorporated[4] though flexibility constraints are added for some commodities to reflect the realities of the international market. Domestic demand functions, with a few exceptions, are specified nationally while spatial price differentials are utilized to reflect differential transport costs faced by each producing region.

Of major interest to the purposes of this paper is the general orientation of CHAC. The multi-level modelling approach utilized allows interrelationships between sectors of the economy to be simulated. In one example of CHAC use [3], it was estimated that the national growth GNP target of 8 per cent (in real terms) required an agricultural growth rate in excess of 5 per cent. The implications of this 5 per cent growth rate on development of arable land and irrigation supplies, and employment were generated. Because employment in the rural sector was insufficient to absorb new entrants (after adjusting for rural-urban migration), employment-creation measures were investigated with the model. Policy issues of this type reflect the fact that the agricultural sector modelled is not highly advanced (technologically) and large-scale government intervention in development is feasible. Policy alternatives involving such large-scale government actions minimize the modelling problems of reflecting farmer behaviour and adjustment rates.

5 SUMMARY

Increased computer capacity and innovations in programming methodology have brought about new opportunities for the construction of large-scale models which reflect much more closely the sector being modelled. Enormous data requirements and highly defined model structures have resulted in a trend towards specific purpose models rather than "generalized policy simulation" models. This paper has discussed

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[4] Incorporation of commodity demand schedules required segmentation of the demand schedule into finite parts. Duloy and Norton [5] present a method by which continuous linear or non-linear functions may be approximated to whatever degree desirable with little increase in the number of rows in the matrix.

problems and choices typical of those faced by modellers and has looked at three examples of large-scale models built for analyses of specific policies in specific economic situations.

Several points can be made in summary:

1. Large-scale programming models are highly specific to the purposes, country and economic conditions for which they are constructed. Comparisons between different models is thus difficult, at best.
2. Problems to be analysed must be closely defined. Simulation of several policy options can be expensive and time-consuming. Similarly attempts to expand the structure and/or data bank of a completed model in order to expand its usefulness may be more difficult than building an entirely new model.
3. During the development process of a model, compromise between theory and feasibility is necessary at many points. In each instance, the choice made affects and restricts potential model uses.
4. Potential users of model results are often (perhaps usually) unaware of the complexity of the model, the strictly defined structural relationships and assumptions, and the resulting restricted scope of model results.

It follows from the above points that effective communication is required on a continuous basis from early planning stages through model usage between funding bodies, policy makers and model builders if expectations and results are to be reconciled. Maintenance of such communication is probably the most difficult task for modelling efforts in which the three groups are essentially independent agencies.

Finally, the development costs and process of large-scale modelling should be emphasized. A well-planned model may take years to develop and may be useful for many years after the prototype is finished. Planning for such a lengthy effort must include provision for continuity. The stated purpose of such projects should be analysis, not specific model-building as such, since original conceptions, and thus requirements, of models may change during development. The financial requirements of such analyses, including development, testing and continuity, are sufficient as to usually be beyond reach for projects not undertaken by governmental or quasi-governmental bodies.

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