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This first aim of this article is to indicate briefly the wide scope and varied nature of the agricultural applications to which computers are currently put in the United Kingdom. Then in order to provide a somewhat more detailed picture of developments in a particular field, two illustrations drawn from agricultural economics show how computer techniques are used to analyse certain theoretical and practical problems. The first is a review of developments in computer applications at the micro-economic level of the farm business, while the second considers the building of computable models at the macro-economic level of the agricultural sector.

It is possible to distinguish two rather different purposes for which computers are used in agriculture. They are either employed primarily to store and process large quantities of data (for example, from farm surveys, experiments or official returns) or they are used mainly as research tools in what can be loosely referred to as operations analysis. An important example of the first type of application is the processing of information gathered by the Farm Management Surveys carried out by the Economics Division of the Ministry of Agriculture. The data is used to assess annual changes in production costs of subsidised products, the effect of tariffs and trade on horticulture and changes in farm incomes, and is broken down according to types of farm and region. Numerous separate surveys for individual crop and livestock enterprises are also made. The Milk Marketing Boards use computers to analyse large quantities of data for their animal breeding programmes, while the Meat and Livestock Commission collects and processes farm and experimental input-output data on animal production. On the economic side, de-

tailed statistics of sales and prices from markets all over the country are processed, the results being published as market reports and price index series.

As basic tools of research, computers are employed in many studies essentially concerned with the allocation of resources under certain constraints. These include programming techniques used by research and advisory institutions for farm business planning, and by commercial feedstuff firms for compiling least cost rations. Another important research application is statistical analysis, including both the routine analysis of experimental data by computer, as well as the use of econometric methods in agricultural economics which has developed rapidly in recent years. Another expanding field of research uses recently developed computer programmes to simulate the complex interactions at work in the natural environment. In the U.K., the Grassland Research Institute at Hurley has pioneered this type of work by modelling continuous systems such as plant/animal relationships in the grazing process. A similar approach is the study of breeding programmes in which computable models are used to simulate the interaction of gene pools of plant and animal populations.

TWO EXAMPLES OF COMPUTER APPLICATIONS IN AGRICULTURAL ECONOMICS

1. Farm Business Planning [1]

The earliest examples of using computers to aid decision-making in the individual farm business came with the introduction of linear programming methods in farm planning. A pratical application was given by Barnard and Smith 1959 (1) who examined the maximisation of farm income on an East Anglian dairy farm given certain resource constraints. Tyler 1960 (2) and Simpson 1960 (3) followed with examples of using linear programming to optimise farm income with farm cases drawn from Kent and Yorkshire respectively. Dorling 1960 (4) illustrated how computer linear programming can solve planning problems in glasshouse crop production, and Stewart 1961 (5) followed up with an example of linear programming applied to an Oxfordshire farm with special emphasis on rotational constraints and labour problems. Further examples of applications in horticulture are given by Simpson, Hales and Fletcher 1963 (6) who used linear programming methods to examine the effect of uncertain prices, and by Lloyd and Perkins 1965 (7) who applied linear programming to glasshouse resource use in a range of possible farm situations.

One of the best critical examinations using linear programming techniques in individual farm planning, which summarised some of the difficulties involved in the early use of computers for farm planning is given by Candler and Musgrave 1960 (8) and shows that linear programming is not only a research tool but is of practical value for solving farm business problems.

This was closely followed by a number of papers which discussed both theoretical problems in the application of computers to farm planning as well as the difficulties of constructing models for practical purposes. McFarquhar 1961 (9) showed how linear programming could be used to deal with the problem of uncertainty and flexibility in the seasonal labour inputs associated with different activities in the farm business. Variation in these input coefficients are shown to have a very strong effect on the total profit which can be derived from a given availability of resources. This paper also discusses the problem of organising data banks required for a widespread and routine use of computers for farm planning and gives some estimates of the time and organisation which might be required in order to set up such a national service of computer farm planning. However, in practice, in the U.K. (or in the U.S.) very little progress seems to have been made in applying on a wide scale the knowledge gained by research workers using computers for farm planing. It is very difficult to get an accurate assessment of the numbers of farms which are actually planned using a computer, and it is easy to gain the impression that computer planning is widespread even though relatively few cases of individual computer-use for farm planning can be cited in any year.

The difficulty of providing a service economic enough to be used for planning individual farms on an extensive scale has led to the development of techniques for producing optimal plans for a wide range of possible farm resource situations; for example, Barnard and Weston 1963 (10) and Barnard 1963 (11). It was intended that optimal farm income plans should be derived, so that in a particular situation reference could be made to a handbook of resource combinations to find the optimal plan for a combination of resources similar to that individual case. It was also hoped that knowledge of how the optimal plans varied as resource combination changed would provide a useful background and an intuitive guide for individual farm planners working in the field without the immediate help of a computer. There are, however, problems associated with this approach. For example, by the time plans can be published for a wide range of resource situations in a given area, prices and input-output relationships affected by technological change may have changed quite considerably and certainly enough to affect the nature of the optimal plan. At the same time if a series of optimal plans are provided for a wide range of resource combinations, product prices, input prices, and physical input-output relationship, the number of possibilities becomes enormous and yet it may still be difficult to find a model with a specific combination of resources close enough to the individual farm situation. The arguments against this kind of planning on the basis of farm models and computer

(1) The authors are indebted to J. S. Nix of Wye College, University of London, for permission to draw heavily for this section on his Annotated Bibliography on Farm Planning and Programming Techniques, J. of Farm Management Assoc. 1 (7), 1969.

programming are summarised by McFarquhar 1961 (9). A further detailed example of the use of linear programming is given by Simpson 1964 (12) in a paper which illustrates the use of the technique on five different farms in Yorkshire, with a full discussion of the practical problems involved.

Other more general papers describing applications of computers in farm planning in the U.K. are Barnard and Camm 1960 (13) and Barnard 1965 (14) which outlines the advantages of using computers in farm planning. Nix 1967 (15) also discusses the advantages and disadvantages of computer planning.

Developments of a more theoretical kind are described by McFarquhar and Evans 1957 (16) who published one of the first examples of parametric programming illustrating how optimal plans varied with a change in total labour input, whereas Tyler 1966 (17) put emphasis on showing how linear programming could be used to produce suboptimal plans which might be more interesting than the first optimum of a linear programming model. Very few examples occur in the U.K. of parametric programming, which show how the optimal solution changes with the continuous input in one variable. The solution usually takes the form of a price map showing the regions or boundaries within which the optimal plan remains constant, or a resource map where the boundaries describe the limits within which the optimal plan changes for a given linear range. McFarquhar 1964 (18) used price and resource mapping to show how models determined for farming situations in East Anglia behaved in face of continuous change in land and labour inputs. No example appear to have been produced so far illustrating the behaviour of a linear programming solution in face of variation of prices on one axis and a resource on another to produce a price : resource map.

Very few examples exist of the use of dynamic linear programming in the U.K. Stewart and Thornton 1962 (19) applied dynamic programming to the optimisation of the organisation of an intensive pig production unit and Cocks 1965 (20) used a multi-stage linear programme to plan the optimal expansion of a farm business taking into account aspects of the Hicksian discounting model and the attitudes of farmers to the consumption : savings problem. One of the few discussions of the use of dynamic programming in the Bellman sense — 1957 (21) is given by Throsby 1964 (22) who discusses the kind of practical farm problems that can be solved using dynamic programming techniques, particularly non-linearity and integer problems. Throsby gives examples of dynamic programming applied to crop rotation, inventory and fodder reserve problems and discusses a replacement model for culling livestock. He explains some of the difficulties of using dynamic programming in practice and emphasises that data requirements are greater than for linear programming. Bukhass and Low 1965 (23) use dynamic programming to solve problems in commercial egg production involving the optimal organisation of housing and length of laying season, taking account of planning period, pattern of egg prices, re-investment problems, etc. The scope for further use of dynamic programming for decision making in egg production is discussed.

No examples appear to be published illustrating the application of integer programming to farm or agricultural problems in the U.K. though aspects of pure integer and mixed integer programming problems were discussed as early as 1957 by Markowitz's and Mann (24). Quadratic programming involving stochastic variables has been applied to a few practical problems in the U.K., the agricultural applications being based on Markowitz's paper on portfolio selection 1952 (25). McFarquhar illustrated in 1961 (26) how quadratic programming could be used to assess the variance, and therefore the risk, associated with the objective function of the linear programming model for an individual farm as income increases from zero to its optimum. Using an arable farming situation in East Anglia as an example it is shown that when risk is taken

into account a slightly lower income may be preferable to the optimum income obtainable from a linear programming model which ignores risks, when all other factors remain constant. An example of the application of quadritic programming in vegetable production where risk is particularly important is given by Camm 1962 (27) describing the application of the technique on a 100-acre farm in Lincolnshire.

The use of game theory for farm decision making problems solved within the framework of the linear programming model is illustrated by McInerney 1967 (28) who shows how the theory of games can be used to take account of uncertainty. The work is extended in a further paper in 1969 (29). Although it does not appear in the U.K. context, a classic paper summarising the application of game theory in agricultural economics entitled « Review and Requiem » is given by Dillon 1962 (30) and should be referred to by thos interested in further applications of game theory at a practical level in farm planning.

Simulation techniques involving the use of computers in farm management research in the U.K. were first described by Hardaker in 1967 (31), who discusses the disadvantages of the technique and possible future uses, and includes a useful list of references. Donaldson and Webster also described in 1968 (32) the advantages of simulation in farm planning with special emphasis on the Monte Carlo method and a further illustration of the use of this method is given by Thompson 1967 (33); Donaldson and Webster (34) 1967 also discussed the use of simulation for the combination of farm enterprises using a 225-acre farm in Sussex as an example. The results of simulation plans are compared with linear programming plans and it is concluded that the technique has a great deal of potential as a " real practical farm-planning tool ". A further article by Webster in 1968 (35) described some of the disadvantages of linear programming in farm planning and discussed the use of simulation involving Monte Carlo methods, again with a practical example of a 200-acre mixed farm, and Harle in 1968 (36) advocates the use of simulation in farm planning and the production of more detailed planning data for simple models instead of developing more complex models to deal with the existing rather simple planning data which exists in the U.K. Dent 1969 (37) gives a general survey of farm planning methods plus a description of the Monte Carlo method, again mentioning the advantages over L.P. but suggesting that the computer time required for exploration of this type of model may limit its use for individual farm planning in the near future. An example of the use of Monte Carlo method in horticultural planning is given by Carlsson 1969 (38) and a further practical example on a dairy farm by Thompson and Paige-Wood in 1969 (39) who seem to think that there is scope for the practical application of Monte Carlo techniques in practical farm planning.

2. Model-building at the national level.

Much recent work in agricultural economics has approached the problems of the rural sector from the opposite end of the scale to that of the farm business, and has examined relationships at the aggregate level. Though the normative techniques of programming which have been applied to farm planning problems can also be employed at the sector level (for example, to determine optimal spatial distributions for crop and livestock production) very little published work has appeared in the U.K. (1). Instead the most widely used techniques for analysing aggregate relationships are the statistical methods of econometrics, based on stochastic models. Much work has been concerned with the determination of supply and demand relationships for farm and food products using regression techniques or modifications of them, all calculations being done by computer. Refinement of some of the data used in such

(1) For a list of references to programming studies at the national level in the United States, see Brokken and Heady (40).

studies is the objective of a computer project initiated recently at Manchester University where the very detailed information provided by the National Food Survey is stored and classified for easy access.

Interest has also been focussed recently on the incorporation of relationships revealed in supply and demand analysis into integrated systems of equations which constitute models of the whole agricultural sector. The main objectives of such exercises is usually to project future levels of production and consumption (and often imports and prices as well). These projections are conditional upon certain assumptions concerning variables exogenous to the sector such as official economic policy, international agreements, and population and income growth.

Two examples will illustrate the different approaches to computer-based agricultural projection in the UK.. Jones' method 1969 (41), was to prepare independent provisional projections of demand, home supply and imported supply for 39 agricultural commodities. The adjustments needed to bring supply and culated and resulted in a series of price changes. Other price changes representing various assumptions about official policy were also fed into the model and the end result was a final forecast of changes in supply and real prices consistent with projected changes in demand. The structure of the model is complex and the operations carried out on the numerous matrices and vectors which are constructed can only be done by computer.

Evans, McFarquahr and Mitter 1970 (42) tackling essentially the same problem start by constructing a physical input-output transformation matrix for 39 products, most of which are agricultural. This shows the inputs required to produce unit output of each product and allows the intermediate demand for these inputs to be calculated for any given level of production. Prices and expenditure elasticities are estimated simultaneously for 27 food products and 1 non-food product from time-series data. Then, given assumptions concerning population growth and income growth and price trends, projections of the future demand for food are obtained. A series of supply response models give production projections, dependent on assumed agricultural policy, and a reconciliation of supply and demand determines the level of imports, though in some cases independent estimates of imports are made. The emphasis through-out is on ease of computability and rigid adherence to quantitative methods.

THE FUTURE OUTLOOK

In the U.K., the problem of maintaining farm incomes in the face of pressure to limit the cost of Exchequer support and allow continued imports of food will become increasingly difficult. It therefore seems certain that more attention will be given to studying the interrelated behaviour of all parts of the farming sector at the national level, involving the construction of computable models in many cases.

In the other branches of agriculture it is difficult to pinpoint which will be the growing points for computer application, though simulation modelling of ecological systems and more sophisticated forecasting of farm incomes and subsidy payments seem likely candidates.

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