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REQUIREMENTS FOR CONTRIBUTIONS

Articles in the field of agricultural economics, suitable for publication in the journal, will be welcomed.

Articles should have a maximum length of 10 folio pages (including tables, graphs, etc.) typed in double spacing. Contributions, in the language preferred by the writer, should be submitted in triplicate to the Editor, c/o Department of Agricultural Economics and Marketing, Private Bag X250, Pretoria, 0001, and should reach him at least one month prior to date of publication.

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Models in agricultural economic research

by

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INTRODUCTION

There is a growing need for models

The modern age of man is characterized by a shortening in entropy time and by an increasing ability to affect, even to destroy, his environment. The first characteristic calls for innovations in the decision making process because new occurrences appearing at progressively shorter intervals require "some quick thinking". The second characteristic requires an awareness of the larger systems because "partial optimization" is becoming less and less efficient - even dangerous. The application of models in decision-making is an important instrument in obtaining these objectives.

Other factors are, however, also important stimulants for the explosion of modelling techniques in research and management. In the sciences of economics and management important philosophical changes have occurred since the turn of the century (22, pp. 5 - 23). The organistic micro-analytical procedures with the associated dogmatic "principles of management" wedded with studies in human behaviour, have produced a more healthy approach to the application of economic theory: "Where possible the administrator should use facts and the descriptive approach in carrying out his functions. The administrator must know when he is dealing with values and normative and prescriptive elements. When appropriate, the scientific method and quantification should be employed to penetrate areas of uncertainty" (22, p. 10). An excellent example of this change is a movement away from prescriptive advice to Bernoullian decision theory (23).

Another factor which favours the application of specific mathematical models in economics, is the quantification of the discipline itself. It can, without doubt, be stated that economics has moved from the realm of a philosophy to the realm of a science. The availability of new techniques, a by-product of World War II, is another factor influencing the widespread application of mathematical models in research. Last, but not least, the introduction of electronic computers made the application of these techniques possible.

This paper will concentrate largely on the use of mathematical models in research. It seems to be the logical choice when applications are discussed in the field of agricultural economics.

The need for a scientific approach in the use and application of models in research

Today research workers in both the natural and social sciences are quite familiar with the use and application of various models in their fields. Familiarity may breed contempt for the need and the prerequisites of a scientific approach. A scientific approach recognises the function of the model in the research process and follows a purposeful procedure in the development, use and application of models. Deviations from this procedure may result in one of various problems, for example:

(i) An incomplete specification of assumptions, thereby including a subjective bias in the research;

(ii) an incorrect structuring of the problem under study thereby stating an irrelevant or erroneous hypothesis to guide the research;

(iii) an incorrect specification of the objective function thereby diminishing the applicability of research results (i.e. the specification of a deterministic model when a Bayesian approach should have been applied).

The use of models in research involves more than the application of sophisticated techniques to problem solving. It is today a part of the philosophy of scientific method in research. A sophisticated model does not sanctify a poorly formulated research project with the blessings of a "scientific approach". The ultimate result is still worthless but, perhaps, with a perverse side-effect favouring the offending research worker. It would require an ingenious colleague to untangle the arguments of a sophisticated model (the structural logic) from the arguments of the specific research (the systems logic). In the meantime the offender is rendering a disservice to a specific approach in research because even if his co-workers may be impressed by his methodological versatility in research, they may have a good idea of the value of his results. On the other hand, a correct incorporation of models in research may enhance the ability of research workers to abstract from the real world and to make valuable contributions to the existing body of knowledge.

THE SUBSTANCE OF MODELS

What is a model?

"A model is a representation of reality intended to explain the behaviour of some aspect of it" (1, p. 145). It is a simplified exposition of a process or a system in which only those characteristics, considered to be of direct relevance to a specific problem, are included.

The appropriateness of a model lies in the abstraction of relevant processes in order to allow the researcher a closer scrutiny of the specific area in the same way as a microscope magnifies a cell in the study of this part of an organism. Conversely, it may be equally difficult to describe all the real world processes from the workings of one model as it is to describe the organism from the restricted knowledge of the cell.

There are three basic types of models namely iconic, analogue and symbolic models (2) (3, p. 21) (1, pp, 150 - 153).

Iconic models are physically similar to the real system as far as the relevant properties are concerned with only a transformation in scale as the main difference. Examples of these models are feeding trials and agronomic field trials in agriculture and three-dimensional models of ships, bridges and buildings in engineering. Examples of two-dimensional iconic models are maps, charts and graphs.

Analogue models use one property to represent another property in the real world. The correspondence between the physical model and the subject becomes more abstract. An example of this kind of a model is where electrical circuitry and electrical current represent a real system such as water flow.

Symbolic models use the logical form in the presentation of a structure. The logical (abstract) form is distinct from the physical form and it refers to "....things or ideas following a pattern, order, or internal connection ..., the association can be expressed as a generalization, where relations depict what several analogous (but physically different) things have in common" (4, p. 56). Word symbols or mathematical symbols can be used in the presentation of these models. Examples of these models can be found in the theory of quantitative economic planning (5) (6), work in operations research (7) (8) (9) and work in systems analysis (3). Economic theory is another example of a collection of symbolic models. In the past, word symbols, strengthened by iconic models (i.e. charts, graphs), were the main medium for structuring economic theory [see, for example, Marshall, (10)], but mathematical symbols are becoming more and more important in the expression of the theoretical structures (see Chiang, 11).

The use and application of models have three interlinking facets which have to be considered beforehand, namely, firstly a set of assumptions which forms the foundation of any model; second, the structure which forms the walls; and thirdly a purpose which forms the roof. Together they present an image (12) of the real phenomenon and they are co-equal in importance for a correct approach in the use and application of models.

ASSUMPTIONS IN MODEL BUILDING

The fact that economic theory is structured by economic models was mentioned earlier. Arguments on the need for realistic assumptions in economic theory are, therefore, also applicable to the formulation of models. What is the purpose of including explicit assumptions in model building? There are three purposes: Firstly, an explicit formulation of assumptions is required in order to prevent an implicit bias in the model; secondly, assumptions define the scope or outer framework of the model - assumptions may, therefore, serve as a "plug" or contact point, by which means a specific model may be included into a larger systems framework; and thirdly, assumptions may serve to pinpoint weaknesses in the model and this can lead to further research in the specific field covered by the assumption.

What is the importance of realistic assumptions? Friedman was concerned with the realism of a theory in his discussion on the methodology of positive economics (13). He concluded that realistic assumptions are not a prerequisite for realism of a theory. The accuracy of the prediction resulting from the theory is the important factor. The role of assumptions is, according to him, to clarify rather than to represent rules: "In seeking to make science as objective as possible, our aim should be to formulate the rules explicitly in so far as possible and continually to widen the range of phenomena for which it is possible to do so" (13, p. 21).

Is the realism of assumptions therefore a superfluous requirement for model building? In a comment on Friedman's observations, Nagel specified three examples of unrealistic assumption which may diminish the value of a model (14):

(i) A statement (assumption) may mention only some traits actually characterizing an object, but may ignore an endless number of other traits also present;

(ii) a statement may be unrealistic because it is either false or highly improbable on available evidence;

(iii) a statement may be so strictly constructed as not to be applicable to any actual situation.

Judging these three examples of Nagel in relation to model building, failure through the first, means an incomplete definition of the scope and weaknesses of the model which render the model less useful in a larger systems analysis. Failure through the second, means incompatibility with existing research results. Failure through the third, means an inability of the model to produce any positive contribution to the existing body of knowledge. In summary it can, therefore, be concluded that the three examples of Nagel may serve as a guide in the ex ante stages of model structuring. Friedman's argument is, in essence, only of ex post relevance when judging the value of a theory (or a model).

THE STRUCTURE OF MODELS

The following discussions will concentrate on symbolic models; more specifically the mathematical model.

Assumptions concerning the real world are of special importance in the specificationof a relevant structure for a mathematical model. Research results, the purpose of the study and the decision environment (15, p. 131) are other factors of importance. Ignoring the distinction between the application of formal models with a specified algorithm and those models characterized by a so-called simulation approach, the general structure of models can be categorized with respect to each of the following characteristics:

(i) Linear and non-linear models;
(ii) deterministic and stochastic models;
(iii) discrete and continuous models;
(iv) static and dynamic adaptive models.

(i) Linear and non-linear models

The simplest example of a linear model is linear programming with a linear objective function and linear constraints (9, pp. 61 - 99). The general form of this model is as follows and it is solved by the simplex algorithm:

$$\max \text{ (or min) } Z = CX$$

$$\text{subject to } \quad Ax \ (\gtreqless) \ b$$

$$\text{and } \quad X \geq 0$$

The standard form of a maximizing non-linear programming problem is to optimize x^x by:

$$\max \quad f(x)$$

$$\text{subject to } g_i \ (x) \ (\gtreqless) \ 0$$

$$\text{and } \quad i = 1, \ldots, m$$

Examples of non-linear programming (N.L.P.) models are quadratic programming and geometric programming (9) (16). An example of an algorithm in non-linear programming is the sequential unconstrained maximizing technique (17, pp. 610 - 613).

(ii) Deterministic and stochastic models

Deterministic models assign single valued expectation to the planning process. Examples of such models are the specific models discussed under (i).

Stochastic models make the explicit assumption that a degree of randomness exists in the future outcome of events. Application of some Monte Carlo (variance-reduction) methods is an example of procedures for attacking these problems (17, pp. 914-915) (18). Markov chain methods are examples of attacking a stochastic process over time (9, pp. 241 -250).

(iii) Discrete and continuous models

The problem of discreteness versus continuality in structure manifests itself in a variety of real world situations. An L.P. result may advise the research worker to use for example, 0,5 tractors to a farm. The application of integer programming procedures (17, pp. 445 - 511) is an example of an approach to cope with discreteness in planning the physical form. Discreteness in the converging characteristics of specific models is exemplified by the simplex algorithm while continuality is exemplified by the Kühn-Tucker conditions in non-linear programming (16, pp. 22 - 61) (9, pp. 46 - 53). Discreteness in stochastic models is exemplified by the Markov and Poisson processes (9, pp. 245 - 255) and the Monte Carlo method is an example of continuality. In dynamic models, the dynamic programming model (the Bellman model) is an example of a descrete process [19] and the Pontryagin maximum principle (9, pp. 212 - 240) is an example of a continuous process.

(iv) Static and dynamic adaptive models

In a discussion on general systems theory Boulding identified nine levels of systems, ordered from the lowest level to the highest level of sophistication (24, pp. 83 - 97). Only the first three are of importance in this discussion which is an indication of the state of the arts in model structuring. Boulding's norm was the ability of a system to act, to react to, adapt to, communicate with and control its environment. The first level is that of statics. Models such as L.P. and N.L.P. are examples of static models. The second level is that of dynamics. An example of a dynamic model is the Bellman model as mentioned earlier. This model states that in a T-stage decision process, after a number of stages (t), the effect on the objective of the remaining T-t stages of the process depends only on the state of the process at the end of the t-th stage and subsequent stages.

The (Bellman) dynamic programming model forms an important basis of a study of adaptive processes in economics [20].

The inclusion of feedback (information) systems brings the discussion to the third level, namely, that of a cybernetic system (21, pp. 331 - 369). An example of cybernetic system in the real world is a thermostat. The transmission and interpretation of information is an essential part of these systems.

The structure of a specific mathematical model may display any combination of the above-mentioned traits. It is also common practice to adopt a model with a specific combination of traits for use in order to attack problems displaying completely different traits. It is, for example, possible to optimize a non-linear production function by means of linear programming. By including probabilistic values in the objective function an L.P. can be used in situations of uncertainty.

The game theory technique is another approach for attacking stochastic situations (27). Other approaches for uncertainty are probabilistic sensitivity analysis, risk programming such as chance-constrained programming, two stage programming, stochastic linear programming and transition probability programming. Decision-theoretic models (such as adaptive programming) are other examples of extensions of L.P. models which can be used in stochastic situations (8, pp. 197 - 261).

Dynamic characteristics are assigned to linear programming through the incorporation of a recursive relation in the model. These models are called recursive linear programmes (25). Other extensions of linear programming such as the decomposition procedure (26) (8, pp. 52 - 73) may widen the scope of applications for the simplex-algorithm. Before choosing any of these procedures the relative efficiency and purposefulness of the specific model should, however, be compared with other models of closer structural characteristics.

The purpose of the model

The purpose of the model is associated firstly with its function in the research process and secondly with regard to the real world phenomena it should help to solve.

MODELS IN THE RESEARCH PROCESS

The function of models in research

There are two main approaches in agricultural economic research. Firstly, the empericism (inductive approach) as proposed by Bacon and carried forward by such exponents as John Stuart Mill and Karl Pearson. Secondly, the normative (deductive) approach as proposed by John Dewey and expressed by Salter (28).

The empiricism rejects any idea of an *a priori* hypothesis and states that knowledge starts with sense impressions and the perception of fact. The scientific method consists of the classification and tabulation of facts, induction to intermediate axioms and induction to laws (29, p. 10). Even formal logic is rejected in this approach. An important objection against the inductive method in research is in the assumption that the researcher should abstain from any anticipation of future outcomes. It is highly improbable that researchers can abstain from following "a hunch", thereby incorporating implicit hypotheses in the research process. Another objection against this approach is its neglect of a purposeful problem solving approach. To reveal knowledge is a sufficient objective for the research worker following this approach.

The normative (deductive) approach relies strongly on an *a priori* hypothesis and has as its final objective the solution of problems. This approach is therefore, the most relevant for attacking the agricultural economic problems of today. By stating the hypothesis explicitly the bias of the research worker is exposed and the research process is supplied with a meaningful framework.

The hypothesis formulation can be divided into three steps, namely, the problematic hypothesis, the diagnostic hypothesis and the problem-solving hypothesis. At the first step the problem is delimited, at the second the failure and success elements are specified and at the third a solution is proposed (30, pp. 88- 89).

The application of so-called descriptive models in the first and second steps and normative models at the third step illustrate the relevance of models in research. Models can serve as an hypothesis with respect to the structure of a process or system and can be used to analyse the functioning thereof in order to discover "bottle necks". The application of input-output analysis in a regional analysis to discover problems in resource flows is an example where a descriptive model can be used to formulate a problematic and diagnostic hypothesis. The applications of various fixed target and flexible target models in quantitative economic planning (5) are examples of normative models serving as problem solving hypotheses.

The scientific method in the use of models in research

The scientific method in the use and application of models can be divided into a judgement phase, the research phase and an action phase (31, pp. 25 - 39). In the judgement phase the outer framework of the problem under study is delimited, an initial set of assumptions is specified and the purpose and objectives of the study are specified. The formulation of a relevant hypothesis and, therefore, the decision on the models to be used, is also carried out at this stage. This process is best accomplished by the use of diagrammatic models where major sub-systems, important components and relationships within each sub-system, links between sub-systems, important environmental variables and control points are specified (3, pp. 25 - 25).

In the research phase the construction of the model and the collection of data are carried out. Observation and experimentation to test the hypothesis (and therefore the model) and systems synthesis which gives a solution to the original problem, is also part of this stage. It is at this stage that the model is validated in relation to the specific purpose for which it was constructed and varified in relation to the body of economic theory and other economic knowledge (3, pp. 27 - 28).

The action phase consists of making conclusions and recommendations based on the results of the first two phases and on the decision-making process it should serve. The importance of this phase is often overlooked by research workers. It is at this phase that the model should answer to its purpose. Usually its purpose is to inform the decision-maker(i.e. the farmer) of alternative courses of action, the results of these actions and the requirements for these actions. It should not produce a prescription, but rather advice. Experimentation with the model must form a central part of this phase. Experimentation includes, for example, comparisons of alternative courses of action, comparisons of the results of changes in the level of a single input, exploration of response surfaces generated for different input combinations and exploration of response surfaces generated for different price levels.

In conclusion it can be stated that the value of a model is situated both in its descriptive and its normative capabilities. A decision-maker should be free to make up his or her own mind. For example, the value of linear programming is situated in both its post-optimal routines (descriptive device) as well as in its optimizing characteristics (normative device).

FIELDS OF STUDY IN MODEL BUILDING

Operations research and systems research

Since the birth of mathematical analytical techniques the terms operations research and systems research have been used somewhat interchangeably. Operations research has been defined in the following ways (1, pp. 132 - 133):

(i) A scientific method for providing executive decisions by means of a quantitative method;

(ii) the use of techniques associated with it, such as queuing theory, inventory theory and linear programming;

(iii) operations research is what operations researchers do;

(iv) applied decision theory.

Taking into account the presentation in the previous section (i.e. "the decision-maker should be free to make up his own mind") it would seem as if the fourth definition is acceptable, in that operations research is applied decision theory. It is also the science which is nearest to the concept of a universal truth (24) when considering its wide field of applications (17).

In operations research a well established set of techniques are used. This is also the main distinction between systems research and operations research. In systems research, systems simulation is the main technique, where the structure of the model is not predetermined but is a function of a research process, called systems analysis. During this process the system under study is analysed and a quantitative structure is specified. When a specific quantitative system, developed in systems analysis, becomes universally accepted, then such a system moves into the realm of operations research.

Operations research and systems research are the two disciplines within which the use and application of models are studied. The enormous body of literature covering these two disciplines can be found elsewhere [for example, (2) (8) (9) (17) (3)].

Research requirements in the application of mathematical models

There are three prerequisites for the correct use of models in agricultural economics:

(i) A sound knowledge of economic theory is of prime importance because economic theory may serve as an initial hypothesis.

(ii) An understanding of certain basic mathematical principles - a depth of knowledge is not required here because the specialist in O.R. should supply it.

(iii) An ability to communicate and co-ordinate with scientists in other research fields. Relevant systems may traverse a wide spectrum of scientific disciplines. If the research worker is unable to communicate and work with his fellow scientist in other disciplines, his ability to construct relevant models in correspondingly dimished. He may include unrealistic assumptions in his model and/or specify a structure which deviates completely from the real world phenomena.

Granted that the use and applications of models will become more widespread in the future, these requirements place an important specification on the type of education future researchers in agricultural economics should receive. There is a danger in producing agricultural economists with an excessively specialized knowledge. In education, as in model building, we should consider the total system and we should supply the student with the required links to other disciplines. An extension of the required post-graduate studies for a master's degree in agricultural economics to a two-year non-thesis option may solve the problem of constraints on educational time. It is already allowed in other departments at the University of Stellenbosch. The requirements for a mathematical background can easily be overcome by a specialist course in differential and integral calculus, a short course in matrix algebra and in statistics. This can be accomplished by a one or two year study as undergraduate: or by introducing specialist courses in the post-graduate study program.

CONCLUSION

In conclusion the following comments on this review can be presented:

(i) Due to the growing complexity of the decision -making process it can be expected that the use and application of mathematical models in agricultural economic research will grow in importance.

(ii) Model application should follow a scientific approach. This approach includes the correct specification of assumptions and the structure as well as an overall research process which can answer to the purpose of the model.

(iii) More emphasis should be placed on supplying information to decision-makers rather than to use the models to supply prescriptions.

(iv) The consideration of the total system is even more important in model building. Partial optimization is "out".

(v) The use and application of models in research places an important requirement on the kind of education future research workers should receive.

REFERENCES

1. MILLER, DAVID W. and MARTIN K. Starr. Executive decisions and operations research Prentice-Hall Inc. Englewood Cliffs, New Jersey, C 1969.

2. ACKOFF, R.L., S.K. GUPTA and J.S. MINAS. Scientific method: Optimizing applied research decisions. John Wiley, New York, C 1962.

3. DENT, J.B. and J.R. ANDERSON. Systems analysis in agricultural management. John Wiley, New York, C 1971.

4. GIBSON, W.L. Jr., R.J. HILDRETH and GENE WUNDERLICH, (Editors). Methods for land economics research. University of Nebraska Press, Lincoln, C 1966.

5. FOX, K.A., J.K. SENGUPTA and E. THORBECKE. The theory of quantitative economic policy: with applications to economic growth and stabilization. North-Holland Publishing Company, Amsterdam, C 1966.

6. HEADY, EARL O., (Editor). Economic models and quantitative methods for decisions and planning in agriculture. The Iowa State University Press, Ames, Iowa 50010, C 1971.

7. THEIL, H., JOHN C.G. BOOT and TEUN KLOEK. Operations research and quantitative economics, an elementary introduction. McGraw-Hill Book Co., New York, C 1965.

8. SENGUPTA, JATI K. and KARL A. FOX. Economic analysis and operations research: Optimizing techniques in quantitative economic models. North-Holland Publishing Company, Amsterdam, C 1969.

9. GUE, L. RONALD and MICHAEL E. THOMAS. Mathematical methods in operations research. The Macmillan Co., Toronto, C 1968.

10. MARSHALL, ALFRED. Principles of economics. Macmillan, London, Eighth edition, C 1920.

11. CHIANG, ALPHA C. Fundamental methods of mathematical economics. McGraw-Hill Book Co., New York, C 1967.

12. BOULDING, KENNETH E. The image: knowledge in life and society. The University of Michigan Press, Ann Arbor, C 1956.

13. FRIEDMAN, MILTON. The methodology of positive economics, from Essays in positive economics. The University of Chicago Press, Chicago, C 1953, pp. 3 - 43.

14. NAGEL, ERNEST. Assumptions in economic theory. American Economic Review, May 1963, pp. 211- 219.

15. FOUND, WILLIAM C. A theoretical approach to rural land-use patterns. Edward Arnold, London, C 1971.

16. ZANGWILL, WILLARD I. Non-linear programming: a unified approach. Prentice-Hall, Inc. Englewood Cliffs, N.J., C 1969.

17. WAGNER, HARVEY M. Principles of operations research. Prentice-Hall, Inc., Englewood Cliffs, N.J., C 1969.

18. STUART O.D.J. Die inskakeling van risikofaktore by die beplanning van landbou-ondernemings. M.Sc. (Agric.) thesis, University of Stellenbosch, C 1970.

19. BELLMAN, R. Dynamic programming. Princeton University Press, Princeton, New Jersey, 1957.

20. MURPHY, ROY E. Jr. Adaptive processes in in economic systems. Academic Press, New York and London, C 1965.

21. PERRIGO, A.E.B. Modern managerial techniques. D. van Nostrand Company Ltd., Princeton, C 1968.

22. TOMESKI, EDWARD A. The computer revolution - the executive and the new information technology. The Macmillan Co., C 1970.

23. DILLON, JOHN L. An expository review of Bernoullian decision theory. Review of Marketing and Agricultural Economics, Vol. 39, No. 1, March 1971.

24. BOULDING, KENNETH E. General systems theory - the skeleton science, in Beyond Economics. The University of Michigan Press, Ann Arbor, C 1968.

25. DAY, R. Recursive programming and production response. North Holland, Amsterdam, C 1963.

26. DANTZIG, G.B. and P. WOLFE. The decomposition principle for linear programs. Operations Research, Vol. 8, 1960, pp. 101 - 111.

27. VON MALTITZ, P.J.M. The application of programming and game theory techniques to farm planning. M.Sc. (Agric.) thesis, University of Stellenbosch, 1969.

28. SALTER, LEONARD A. A critical review of research in land economics. University of Minnesota Press, Minneapolis, C 1948.

29. GIBSON, W.L., R.J. HILDRETH and GENE WUNDERLICH, (Editor). Methods for land economics research. University of Nebraska Press, Lincoln, C 1966.

30. TIMMONS, JOHN F. Agricultural development through modifying land tenure arrangements, in I.S.U. center for A. and E.D., Economic development of agriculture. Iowa State University Press, Ames, Iowa, C 1965, pp. 81 - 98.

31. SAATY, THOMAS L. Mathematical methods of operations research. McGraw-Hill Book Co., Inc., C 1959.