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DECISION-MAKING AND AGRICULTURE

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The Role of Models in the Decision Process in Agriculture

Any decision process is a link between thinking and doing, between reflection and action. In order to assess the role of models in the decision process in agriculture it therefore is essential to have a clear idea of the relationship between reflection and action. Put in such general terms the question is not restricted to agriculture. Indeed, most of the concepts and hypotheses presented here probably would apply to any decision process. Yet the expression "in agriculture" has been kept in our title essentially for two reasons. First, as agricultural economists we are mainly interested in problems arising in agriculture. The main theme of our conference is precisely the decision process in agriculture. Second, the experience from which the concepts are derived as well as the examples given below all stem from agricultural economics research.

This paper contends that models, often very informal models, are an intimate part of, and play a crucial role in, all decision processes. Formal models can be useful if they refine this process, i.e., make it more effective. If this premise is accepted, the role of models and of model-builders is clear. They must help the decision process. To support this argument the paper is organized in four sections. The first presents a general model of adaptive behavior which emphasizes the close interrelationship between reflection and action seen as two parts of the same adaptive process. In the second section, two classifications of models built and used by agricultural economists are discussed in the light of the general adaptive behavior model. The study of these classifications leads us to argue that the usefulness of models depends more on the role given to them by the analyst rather than on the type of model used. Accordingly a conception of the relationships between decision-makers, models and model-builders is derived in the third section. All students of decision processes must face two major analytical difficulties (model specification and model validation). These are discussed in the last section, on the basis of the general thesis of this paper.

Before proceeding to the first section we should specify exactly what we mean by the word model. Let us state that a model is a representation – necessarily incomplete – of reality in our mind.[1] Such a broad definition is

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needed because it captures the essential epistemological nature of models and permits assessment in proper perspective of the long-term efforts of economists at building more and more formalized decision models.[2]

1. THE GENERAL MODEL OF ADAPTIVE BEHAVIOR

The purpose of this model is to establish close interrelationship between reflection and action. In other words, the analysis of the decision process requires a model of the decision process itself.

1.1 Agent, environment, goal, perceptions:

A synthetic presentation[3] will be made here starting from fundamental concepts and relating them together. Decisions are made by individuals attempting, through their actions, to modify their situations vis-a-vis their environment. Two interrelated concepts emerge here: the *agent* and *his environment*. These are two subsets of the universe. Because only a fraction of the universe is relevant to the decision of any agent, one would not need to include the whole universe in the environment of the agent at any one time. But it is preferable to do so because one important aspect of the behavior of any agent is the search for information beyond the border of his immediate environment. To fix *a priori* the outer limit of the agent's environment would not permit the model to capture this essential dynamic feature of the decision and action process. As to the border line between the agent and the environment, it is sufficient to postulate that it exists and that it may vary. For instance, it will be useful to consider that a farmer's environment includes, among other elements, sometimes his farm and his family, at other times only his farm; in the latter case the agent then is made up of the whole family without considering the interrelationship within it between, say, husband and wife, or parents and children.

Agents act in order to modify their situation with respect to their environment. Their action is thus postulated to have a purpose. They have *goals*. A major question pertains to the ways in which goals are formed and modified. Before investigating this point further, it must be pointed out that decisions to act are made by agents on the basis of how they perceive their environment and themselves, including their goals and their possibilities to act. Two new concepts have appeared here: their possiblilities to act, i.e., the *feasible domain of actions* and *the agent's perceptions*. Models play a crucial role in these perceptions. Essentially the broad definition of models given in the introduction leads us to argue that these perceptions are models, some vague and non-formalized, others more formalized.

1.2 Perceptions, learning and acting

The agent's perceptions depend upon his past experience, his memory, and the flow of new information reaching him all the time, originating in particular from his actions. Thus learning, which is the modification of one's perceptions, and acting are two intimately related processes. Conscious efforts to learn, such as reading a book or listening to someone, can even be viewed as actions;

this proposition strengthens the argument for a close interrelationship between learning and acting. Indeed, they can be viewed as parts of a single process; we can even learn about learning.

The postulate that all actions, including learning, have a purpose may appear much too rationalistic. After all, we often make mistakes and often learn without trying ("involuntary learning"), for instance, for the simple reason that we did not even know that there was anything to learn. But this criticism does not invalidate the postulate. The purposive nature of action implies only that when taking a decision, the agent does so to reach some goal. It is true that he can be mistaken both concerning his goal (once he has reached it, he discovers that he should have pursued another) and the relevance of his action (it did not permit him to reach his goal). But actually this general uncertainty is taken into account and adaptation to it is an essential feature of the model. Any perception is recognized as tentative, and a wise man often agrees to revise his position. Any action ought to be *controlled*, i.e., its impact should be monitored and due corrections should be made in case of errors or of changes perceived in the environment. A simple example: I have decided to drive to my office – my goal. I may revise this decision if I find out that the road is too dangerous today. I am alert to possible, unpredictable obstacles and prepared to make a detour. In both cases, the action to drive can only be understood if one recognizes that it is taken with the purpose of reaching the office.

1.3 Goal formation and modification:

The nature of goals can best be understood by taking into account the hierarchical relationships between categories of actions. The example of the automobile trip can best illustrate this hierarchy. When someone decides to drive from A to B, his goal is to arrive at B. If he gets there, he clearly will have modified his situation vis-a-vis his environment. His action is to drive there. But this action entails a host of elementary sub-actions: slowing down, accelerating, turning, etc. Each sub-action itself can be split, conceptually *ad infinitum*, into more elementary sub-actions: lifting the foot, changing gear, moving one's arms... At the other extremity of the spectrum the goal "to reach B" can be interpreted in terms of higher order goals. The agent wants to go to B because he has work to do there. He has work to do there because he is engaged in a given project, because he pursues this career, because etc. Any decision to act fixes a goal for the sub-actions necessary to implement this decision. Thus a goal really is an intended action with an expected outcome.

The choice of a goal is a decision. It depends upon higher order goals and the perception which the agent has of his environment and of his possibilities to modify it. Goals can be revised when these perceptions are modified. But where do goals of a higher order come from? Clearly from yet higher order goals. How far up can we go in this hierarchy? Conceptually *ad infinitum* again, but is this a satisfactory answer? Given that goals are intended actions, higher and higher order goals relate to more and more general actions. Is it wise to assume that agents have such very general action projects? Conceptually perhaps, but these are at best very vague. Is it not more useful to

consider that given the impossibility of formulating an infinite hierarchy of articulated goals, agents resort to a temporary, revisable set, and to some general rules of behavior? These reflect the set of values held by the agent. (For the distinction between goals and values see Lewis (1955).) In this perspective, values differ from goals because they are general whereas goals, even when of a higher order, refer to a very specific individual in a given situation at a given point in time. Values transcend situations. They also transcend individuals as one speaks of social values. Note here, however, that the model does not assume that values are fixed once and for all, nor that the agent knows them precisely; nor does the model assume that values are restricted to influencing general, grandiose plans of action. On the contrary, they also influence the most trivial actions. For instance, one uses an extra blanket during the winter simply because it is comfortable to be warm in bed. It is not necessary to look for a higher order goal. The ways in which values influence the formation of goals deserve to be specified further, but this article is not the appropriate place. Let us remember only that our model remains vague on this point.

1.4 Adaptive behavior and the role of models:

The model of decision-making elaborated so far can be summarized as follows:

At any point in time the agent has a perception of his situation (vis-a-vis his environment), of his goals, of his possible actions and some idea of the values he holds, including, possibly, contradictions among these values.

All these perceptions are changing because the objective situation of the agent changes and because he continuously learns more and more about these various elements. His behavior is a continuous adaptation process. He acts and thus adapts to changes in his environment and in his perceptions. In the same process, he learns more and adapts his goals and his perceptions. At all times, he knows that his perceptions, his knowledge, are provisional and subject to revision. In a way, he is continuously in the process of revising his knowledge, he destroys old models and builds new ones. Such a view of knowledge and actions as a continuous process appears in complete agreement with the findings of Bachelard, a philosopher of science and Piaget (1968), a student of the elaboration of cognitive processes among children.[4]

2. CLASSIFICATIONS OF MODELS BUILT BY AGRICULTURAL ECONOMISTS

Several classifications have been used to sort out the various types of models used by economists.[5] In agricultural economics two classifications seem to have played an important role in the discussion of the relative merits of various types of models. These discussions on the merits of models are useful to reveal the role assigned to them by those who build and use them. Some authors have distinguished between positive and normative models. Another useful classification is based on criteria relative to the mathematical structure of the model or to the source of data used to estimate their parameters.

2.1. Normative versus positive models

The vogue of programming, particularly linear programming, models of the farm as a production unit has led to considerable discussion concerning the use of such models. In the U.S., large research projects undertaken to study the impact of new agricultural technologies and farmers' supply response (Dairy Lake State Study, NC54) were based on linear programming models of representative farms. Similar efforts were undertaken in numerous other countries. All these large models produced highly unrealistic results which were considered as such by the researchers involved. As a result, the question of the relevance, and hence of the real nature of these models, which had consumed large amounts of research resources, had to be faced. It then was often argued that such models were "normative", i.e., that they indicated what farmers should do. A somewhat more sophisticated variant of this interpretation calls such models "conditionally normative" (if farmers really want to maximize their income, this is what they should do). This interpretation is closely linked with the use of these models in farm management advisory work. The existence of an objective function to be maximized (or minimized) leads one to speak of optimization and hence to present the results as norms[6] to be fulfilled by the farmers. Such models are contrasted to other models which do not postulate an optimizing behavior, i.e., which are viewed as representing how farmers actually behave, rather than how they should behave. Examples of the second category are econometric supply models which postulate the existence of a supply function without any specific optimizing assumption concerning the producers' underlying behavior. Such models are then called positive or descriptive models.

Glenn Johnson (1976) has argued strongly that these labels are not appropriate because they reflect only a popular version of nineteenth century philosophy. An outright positivistic philosophy of social sciences is not tenable today. Social facts and social values are known to be intimately related, hence values cannot be excluded from the realm of social science investigation, and hence purely positive model of economic behavior do not exist. They are always based on some assumptions – perhaps implicit – relative to values. Conversely, the assumption that farmers maximize income does not make the model purely normative, as is well illustrated by the label "conditionally normative". Johnson argues further that values must be investigated and that an objective knowledge about them – including agreement on what is good and bad – can be obtained. Without pushing this argument further, we will use the expression optimization model instead of normative model and put the word "positive" between quotation marks. Let us examine how this distinction between these two types of models stands in the light of the general adaptive behavior model adopted in this paper.

First, it must be emphasized that the use of optimization models does not necessarily imply the production of norms (or goals). In farm supply analysis, for instance, the rationale for building a model of a representative farm, as illustrated directly by the word representative, is to capture the essential features characterizing the economic workings of the farm as a production unit. Consequently, a linear programming model of a farm built to understand

farmers' supply behavior must be viewed as a behaviorial model. As any model, this one is based on an assumption to be tested, in this case that farmers seek to maximize one objective[7] subject to a set of constraints. Such a model does not imply that farmers are only worried about income; constraints can render an account of other objectives, such as the search for leisure or for security. Furthermore, the results of such models must not necessarily be viewed as goals. If the represented farmer does not behave as suggested by the results of the model, he is not necessarily wrong. Rather the model is not an accurate representation of what it purports to represent.

Whether or not a farmer should modify his decision and would find it advantageous to behave as indicated by the model results is an important question in farm management work. This can be decided only by the farmer, possibly after a discussion with the model-builder, once he has reassessed his goals, the situation of his farm and his environment, and his feasible domain of action. Such a prescription would be supported wholeheartedly by any experienced extension worker and is in full accord with the general adaptive behavior model. Thus, if one speaks in terms of norms, the main purpose of an optimizing model is not to produce goals ("norms") but rather to question the "norms" implicitly, or explicitly, accepted by the decision-maker.

What about the so-called "positive" models? Do they play a different role in the decision process? To be of any use they must be a fairly good representation of some segment of the economy. Hence, they should be useful to one or several decision-makers in understanding his, or their, environment or, more precisely, situation vis-a-vis environment. It is true that the goals of the decision-makers do not appear as such in a "positive" model. But, from the general adaptive behavior model, we know that goals are projected actions with expected outcomes. A "positive" model can be very useful in assessing the likelihood of such expected outcomes. As such, to continue to speak in terms of norms, the model will be useful in questioning the "norms" of the decision-maker. This fundamental similarity of functions of these two types of models, distinguished earlier precisely on the basis of their purpose, arises from the fact, pointed out by the general adaptive behavior model, that goals are intimately related to the situation of the agent.

2.2 Classification of models according to their mathematical structure or to the source of their data

In this section, three broad generations of models which have appeared one after another in our profession will be discussed briefly. The emergence of a new generation is proof that previous ones were not wholly satisfactory. The fact that no new generation eliminated the previous ones shows that there is not one privileged category of models. To distinguish only three generations is of couse to paint a picture with very broad strokes of the brush. This will, however, support the main thesis of this paper: whatever the model used, what matters most is the role given to it in the analysis which it supports. Ultimately, this role must be viewed in the general context of the decision process(es) served by the analysis.

The three broad generations to be discussed here are econometric models

based on statistical inference, programming models, and general simulation models. These labels admittedly can be questioned. They are meant to help clarify the discussion.

Econometric models based on statistical inference appeared first in the 1920's. They can accommodate fairly robust hypotheses of economic behavior and have the advantage of permitting the reader relatively easy access to the data. For instance, an interested reader could, if he wished, check the computations or trace the consequences of a change in the original set of hypotheses. Hence these models have the appeal of some objectivity. This advantage should not be overstated. It is this author's personal experience that considerable judgment is involved in building such models.

Programming models, first developed in the 1940's, began appearing in the agricultural economics profession in the 1950's, and were in full vogue in the 1960's. Two major features distinguish them from the first category: the source of their data and their mathematical structure. Statistical inference is not used to estimate their parameters which are built up from a variety of sources. Since, furthermore, they entail a much greater number of parameters, peers'* control of data and of computation procedures is made almost impossible. The existence of an objective function forces the model-builder to specify further his hypothesis relative to the behavior of the economic agent studied (say the farmer) or the set of relationships between economic agents within an economy (as in an inter-regional competition model). This loss of robustness can of course be viewed as a disadvantage. On the other hand, programming models are very efficient instruments to organize coherently a huge mass of information; the very specificity and explicit character of the assumptions on which they are based lead to their thorough discussion – a definite advantage.

General simulation models appeared in the late 1960's. The word simulation may lead to confusion. The other two categories of models can also be used to simulate the functioning of what they are supposed to represent, but in the latter category this is the unique objective. Their advantage is their flexibility both in terms of data used and of mathematical structure. They are really an outgrowth of system analysis and they have been used mainly as a way to simulate the behavior of a system through time on the basis of some assumed relationships between variables.[8] Their purpose is not to test such relationships directly. Yet they may provide an indirect test, as when model results are compared with data on the actual behavior of the system and differences are interpreted.

System analysts, and scientists who have worked in collaboration with them, are convinced of the superiority of these general simulation models in assisting decision-makers. The outstanding publicity given to the book *Limits to Growth*, which was based on such a model, tends to support this claim. This book has been severely criticized by other scientists for lack of rigor in the conduct of the research. I feel that such a bold attempt at modelling the world was bound to produce only very rough results yet its great merit lies

* See previous para - (edit).

precisely in the controversy it engendered. It called public attention to important issues and demonstrated that we really know little about them.

A general conclusion about these various types of models stands out. No type is inherently superior to another in assisting decision-makers because decision makers use all types of available information. We should not restrict ourselves to specific kinds of data. At the same time we should be conscious of the uncertainty surrounding the data we use and of the relevance of this uncertainty. In this respect it may be useful to denounce the slogan often heard in our profession. "No model can be better than the data which go into it". Such a statement seems obvious yet it is meaningless. Criteria for assessing the reliability of data conceivably can be phrased in terms of accuracy statements[9] but the results of the model should be judged in relation to the situation of the decision-maker: What is it that he needs to know about the phenomenon under study? What are the other sources of information? Is the value of the added information provided by the model worth its costs? Given the numerous externalities involved in model construction and utilization, estimating model benefits and costs is very difficult indeed but one should at least recognize this as the ultimate criterion.

It appears from his discussion that the role of models in the decision-making process does not depend upon their mathematical structure or the type of data they use. What really matters is the underlying "philosophy" of the analyst. What are his goals in building a model? What issues does he want to deal with? How well thought out are they? What light does the model throw on these issues? What questions remain open? Why? The choice of the most appropriate model depends upon the answers given to these questions.

3. DECISION-MAKER, MODEL, MODEL-BUILDER

The role played by the analyst in the conduct of the analysis in the previous section has been emphasized. Though no novelty, it deserves to be repeated. The purpose of this section is to better specify the role of the analyst, his relationship with decision-makers, and the possible utility of models in this relationship.

3.1 Place of models in the decision-making process

In the adaptive behavior model, an economizing principle is implicit. To assert that actions are taken in the pursuit of goals implies that agents are interested in reaching their goals. Since this always costs something, i.e., sacrifice in terms of attainment of other goals (there are trade-offs between goals), it is safe to assume that agents seek to minimize such costs. But as already emphasized, this behavior takes place in a climate of general uncertainty where information has a cost. Models thus are used so as to act more efficiently. Provided that they can be relied upon, elaborate models will be better than rough ones because they are more efficient as ways to organize a multitude of information in a relevant manner. The proviso, of course, is essential; keeping this in mind, progress can be seen as leading toward greater model formalization[10] as a way to reach better coherence between goals and actions. Such is the fundamental

role played by models. But the argument applies here to the models which are in the mind of the agent, which form his "perceptions" of his environment and of himself. What happens when the formalization process has gone so far that a division of labor is necessary? How will model-builders relate to decision-makers?

3.2 Relationship with decision-makers

In order to build realistic and comprehensive models, analysts will find it advantageous to work in close collaboration with decision-makers. Experience shows, however, that this is easier said than done, perhaps for want of a clear understanding of each other's respective decision and action domains. Furthermore, one can justly argue that social scientists, such as agricultural economists, seeking to sort out the fundamental economic problems of agricultural development, play a useful role even though they do not relate their work either directly or indirectly to any specific category of decision makers. One should, however, take care not to draw fallacious implications from such an argument. The usefulness of models obviously depends upon the quality of the new knowledge which they help to produce. The social relevance of this new knowledge must ultimately be judged from the point of view of the decision-making processes to which it contributes.

3.3 Non-neutrality of social scientists

The claim that social scientists can be fully objective, meaning here that they are neutral with respect to the phenomena which they analyze, can no longer be supported, If they have any value, models will be useful to some decision-makers. They will help some to understand their own situation and action possibilities better than others. Hence they will influence their actions. Furthermore, with any model of society can be associated an underlying implicit ideology which it strengthens. This has an impact on social values and hence on the "social game". We thus reach the conclusion, which is becoming increasingly accepted, that pure, scientific objectivity is an illusion, at least in the social sciences. But Myrdal's recommendation (1969) that social scientists should spell out their own values is not adequate to the problem at hand here. No one fully knows his own values. Any discursive presentation always sounds too noble, probably because it does not take sufficient account of internal contradictions within the set of values held by any individual. Actually our values are revealed by our actions. Thus social scientists, whatever the degree of sophisitication of the model which they use, should be conscious that they are ideologically involved, and that a high degree of sophistication may obscure the real values held by the analyst. Hence the least which can be expected of model-builders is that they clarify in their own minds their position in the "social game" as best they can and make it as explicit as possible. This is where discussion among scientists having different ideological biases can be very useful. In general, the choice of the boundaries and of the elements of the system which the analyst chooses to represent is often very revealing of his ideological bias. For instance, the set of interrelationships between social groups in the development process is often neglected by

model-builders. For a conscious effort to analyze it in the case of the Kosi region in Bihar (India), see Biggs (1973).[11]

Marxists have a different conception of scientific objectivity. They argue that the evolution of society obeys the objective laws of class struggle. In this case the model-builder's objectivity consists in accepting this postulate and his task is viewed as that of prescribing the consequences for actions of these objective laws. For instance, a planning model must yield the optimum set of actions to be undertaken. This presentation may not do full justice to our Marxist colleagues' position. Whether the adaptive behavior model, which in my view applies also to the case of a centrally-planned economy, is compatible with Marxism or not remains to be seen. The views on scientific objectivity, however, appear impossible to reconcile.

But we share one conviction with Marxists: The analyst is not neutral in the social game. If he works directly with decision-makers, he reinforces their power, at least in the short run. If he does not work directly with them, he stengthens the underlying ideology of his own position, particularly if he does not attempt to expose the internal contradictions of his own position. Besides the ideological question, model-builders face analytical difficulties which are discussed in the following section.

4. MAJOR ANALYTICAL DIFFICULTIES

Any model-builder faces difficulties in at least two phases of his work: the specification and the validation of his model. Since these questions arise for all models, they will be discussed here.

4.1 Model specification

The first question to be answered in constructing a model is: What level of approximation is accepted? The answer, of course, depends upon the purpose of the model. Two conflicting pressures must be reconciled here: the model should be as close a representation of the studied phenomenon as possible; but too intellectually ambitious a project may be less fruitful than a more modest one.

The following unfortunate experience of this author illustrates this point. Research on the obstacles to the adoption of intensive forage production techniques by dairy farmers in Eastern France led to the hypothesis that technical uncertainties in the production process itself were such that many dairy farmers could not take the risks associated with these techniques. A simulation model was built with the purpose of testing this hypothesis. A programming model was deemed to be inadequate, since what mattered in that case was the cumulative effect of uncertainties in the sequence of elementary production processes (grass, planting, growth, grazing, growth again, grass and other foodstuff consumption by dairy cows, milk production . . .).

A production model synthesizing available biological information was built to represent the production process of a specific cowherd on an ordinary farm for which data on total daily milk production were available and were used for testing model results. After much effort, a reasonably good model simulating the first hundred days of the grazing season in the spring and early

summer was constructed. But this was a far cry from what was needed to test the general hypothesis on which the whole project was based. The model really pointed out large gaps in biological knowledge. For instance, the relationship between rainfall and grass growth is both obvious and impossible to specify accurately. Hence, it was impossible to derive the probability distribution of milk production from data on rainfall variations. The cumulation of such obstacles led us to abandon the project.

This failure clearly was due to an over ambitious project. However, even though no formal test of the hypothesis could be conducted, the familiarity which we acquired with the phenomenon studied in the process of building and refining the model convinced us of the validity of our hypothesis. But how to communicate such a conviction? How to submit it to the criticism of our peers? How to specify the hypothesis so that its domain of validity could be assessed more precisely?

These questions call for building new models at various levels of specification. Which ones exactly, we do not know. This doubt should at least be sufficient to illustrate that "overkill" is a danger in model building. The level of approximation to be accepted, and hence the specification of the model, depends upon the quality of the knowledge pertaining to the phenomenon studied and its relevance to the issues to be clarified.

4.2 Model validation

To validate a model is to accept the hypothesis on which it is based. If one accepts that new knowledge is gained when old mistakes are corrected, it is the validation process rather than the resulting validated model which is really fruitful. For the purpose of action, however, it is a valid model which is needed. Hence the validation process serves two related purposes regarding learning and doing.

With these purposes in mind, what criteria of validation should be used? Of course, one expects that models will be logically consistent. Precisely, one advantage of mathematics and formal logic is to insure internal logical consistency. But to what extent do theoretical concepts correspond to real characteristics of the phenomenon studied? Are those available good measurements of the theoretical concepts? The internal logical consistency of the model enhances but does not guarantee the logical consistency of the analysis conducted with the help of the model. Yet it is the latter which counts.

The above questions lead to a second criterion of validation: How can one compare the model with the reality it purports to represent? Without entering into a philosophical discussion on the nature of reality, let it be accepted that a model is never compared with reality but with another image of reality; which image and which comparison? The first criterion which comes to mind is: Consistency with observation; model results should be compared with direct observations of the studied phenomenon. The model will be valid if its results are reasonably close to the observation. Two questions arise in this respect: What is reasonably close? What is the epistemological nature of these observations? Actually the closeness of the fit can only be judged subjectively. Even statistical models giving a range for a parameter estimate at some level

of significance cannot escape this. As L. Mandersheid has shown very well, there is nothing absolute about a 5 percent or a 1 percent level of significance. Hence, the question to ask is whether or not the model renders an account of observed variations in the phenomenon studied. Whether this account is judged satisfactory or not depends upon the use made of the model, i.e., ultimately on the questions which it answers for one or several decision-makers. As for the epistemological nature of observations, it has been argued that no observation is strictly objective for it depends upon the observer. What he observes depends upon his ideas of what should be observed, hence of his *a priori* knowledge. This point is certainly well taken and one should probably speak of *consistency with experience*. To be valid a model must produce results (logical consequences on one's hypotheses) consistent with one's previous knowledge which had led one to make specific observations. In case of inconsistencies, hypotheses must be questioned and revised to render account of all observations. Experiments – seldom possible in the social sciences, it is true – are for some disciplines powerful ways to generate observations relevant to putting previous models to a serious test. But in this view they are only one category of experience.

Pragmatist philosophers have also suggested the test of workability. A model is valid if it works, i.e., if it leads to the right action. Such a criterion will readily be accepted if one accepts the general adaptive behavior model for which learning and doing are intimately related. But a blind application of this test can be dangerous. A model may "work" for a given situation and yet be invalid in all others while, to be useful, knowledge must have some degree of generality. A moment's reflection will also show that workability is a special case of experience. Hence, the test of workability can be accepted as a necessary, but not sufficient, condition of model validation.

Ultimately these three criteria of model validation (logical consistency, consistency with experience and workability) establish the degree of reliability which can be given to the knowledge thus generated and made available to decision-makers. As reiterated in this paper, knowledge must be viewed much more as a process rather than as a state; a model is not valid once and for all. In the pursuit of knowledge, the more a model raises pertinent questions, the greater its utility. Thus, somewhat paradoxically, the most useful models are those which have the greatest chances of being invalidated. Invalidation, the rejection of hypotheses, leads to correcting one's previous errors. It is the essential step in the learning process.

5. CONCLUSION

If one accepts the proposition that learning and acting are two interrelated phases of the same fundamental process of adaptation, the role of models in decision-making is very clear. Models are the simplified representations of reality formed in the agent's mind, his perceptions of himself and of his environment. Decisions to act are based on these perceptions. Conversely, as a result of his actions, the agent is led to revise his perceptions: he learns. Hence the agent is constantly adapting his perceptions and his actions which are

themselves closely interrelated. He may also learn involuntarily as new information reaches him. In this perspective, models play a crucial role, even though most of them are very informal.

Model formalization can be a source of progress, i.e., of a better coherence between ends and means, provided that it produces reliable and sufficiently flexible models at a reasonable cost.

The role of model-builders is to help decision-makers in building such flexible and reliable models. This can be done in a variety of ways, as illustrated, for instance, by the agricultural economists' numerous modes of operation. A plea can be made here, however, for an "analytical" use of models.[12] By this expression we mean that the analyst should always consider the model as a tool for the analysis of the reality which is represented by the model. For instance, a model is a tool designed to analyze the situation of a decision-maker vis-a-vis his environment. Model results can never be taken as *prima facie* goals. They are only the logical consequences of the hypotheses, either explicit or implicit, and must be critically evaluated as such.

It should perhaps be emphasized that the adaptation process described above does not apply only to individual decision-makers. Collective action is not ruled out; on the contrary the concepts developed in this paper can be very useful to analyze why groups are formed, why they act, why they change membership, why they survive or why they disappear. The limitations of the approach in terms of decision processes must, however, be recognized. To place emphasis on economic decision-making processes implies that one views the economy, and therefore society, as a complex set of decision-makers influencing each other and linked together by a large number of interrelationships. In this perspective, conflicts are normal and recognized as such. The adaptive behavior model does not tell us how conflicts are solved. It does not even tell us which conflicts are important and which ones are secondary in the evolution of the economy and of society. As such it falls short of being a global theory of social change.

NOTES

[1] Some authors would argue that such a definition of the word models is much too broad. They would prefer to distinguish among hypotheses, theories and models. Hypotheses are essentially tentative propositions about reality and as such simplified representations of parts of it. A theory is a structured set of interrelated hypotheses. Models are still more specific. In a way they are specified versions of theories, often taking a mathematical form with specific values of the parameters. Such distinctions are often useful particularly in the process of building econometric models. They can help the analyst to become more aware of what he is doing. For instance, an uncertain estimation of a parameter does not necessarily imply that the mathematical structure of the model should be revised, the failure of a model to capture essential aspects of reality does not necessarily invalidate the theory. Perhaps, one should then wonder what kind of procedure is needed to put theories to crucial test. But this question, albeit important, would take us far away from the main objective of this paper.

[2] One could argue that all economic models are not decision models. Some models are used to represent a set of interrelationships between economic agents without specifically attempting to help any decision-maker. But even those are, in some sense, decision models. In order to be of any value, such models presumably should clarify some issues

for someone interested in those issues, i.e., a decision-maker who will use the information generated by the model in his decision process. Admittedly, this loop is not always closed.

[3]No attempt will be made to acknowledge the numerous intellectual debts incurred in building up my own version of this model. Most of these can be found in Day (1976), Petit (1975 and 1976), and Renborg (1976).

[4]Kuhn's thesis on scientific revolutions (1970), although it emphasizes the discontinuous nature of such progress, is fully consistent with the adaptive behavior model inasmuch as it argues that scientific discoveries occur through the destruction of old paradigms and the construction of new ones.

[5]We will not attempt here a review of the literature on models, not even decision models. For two excellent reviews see Dillon (1971) and Anderson and Hardaker (1972).

[6]In this context the word norms is synonymous with goals and thus differs from values.

[7]This objective may be profit or a farm income or a function of several objectives, as in the case of a utility function.

[8]For a good illustration, see the famous *Limits to Growth* (1972).

[9]For instance, the probability that x falls within $\bar{x} \pm t\sigma$ is α.

[10]As indicated above, model costs also must be taken into account here.

[11]In a letter to this author Biggs wrote: "Models developed for decision making processes in agriculture have not addressed: (a) policy issues of income distribution, (b) technology (in its broader sense to include more than HYV's), (c) accumulation of savings – by whom and invested in what specific items of capital, (d) the broader range of socio-political issues which came into real world policy decision-making (academics can avoid these things but not the civil servants and other policy-makers) . . . ". This judgment may be a little harsh but it clearly makes a point: The choice of phenomena judged to be important enough to be represented in a model depends upon the model-builder's ideological position.

[12]The responsibility for this expression is shared with my colleague, Jacques Brossier, who has written several good papers on this subject. See Brossier (1973).

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