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STRATEGIC MODELS OF WORLD FOOD PRODUCTION AND TRADE

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INTRODUCTION

World food markets seem to be largely determined by the production and consumption patterns of some 20 countries. Moreover, inspection of these patterns in recent years suggests that there are only about half a dozen of these that account for most of the world's exports. In such a situation, where markets are determined by relatively few actors, output and trade may be subject to strategic manipulation. The problem is to determine what effects such behaviour may have on total food production and prices, since this has profound implications for food-short nations. Here we briefly suggest certain behavioral phenomena that one might look for in such a situation and briefly outline some game theoretic models to analyze such behaviour.

Some of the questions that might be treated are these:

- in a competitive market would the major producing countries be likely to produce less than is warranted by their costs of production?
- what kind of collusive agreements could form between producers, or between producers and consumers, and what is the effect on production and prices?
- what are the effects of certain strategic choices on the evolution of different countries' positions in food versus non-food production?

To answer such questions we propose the following three-part modelling sequence:

simple oligopoly model

general equilibrium model with several sectors

multiperiod investment model with effects on growth and reserves.

These models build on each other and involve increasingly more data for implementation.

A SIMPLE OLIGOPOLY MODEL

This model deals with a single commodity such as grain. Countries are divided into two classes: (E) net exporters of grain, and (I) net importers of grain.

The basic data required for this model are (1) the aggregate demand curve for the net importing countries; and (2) the cost functions of each of the net producers. If the cost functions are not known, it could be assumed instead that additional production is costless up to a certain limit s_i, beyond which the country i cannot naturally produce any more.

Let $p = f(q)$ be the aggregate demand and $c_i(q_i)$ the cost of producing amount q_i for each of the countries $i \in E$. The countries in E can be considered as playing a game in which they set their production levels so as to maximize net revenues. Equilibrium is reached when each producer's marginal net revenue is zero, that is, when

$$\frac{d}{dq_i}[q_i f(\Sigma q_i) - c_i(q_i)] = 0$$

The equilibrium outputs q_i^* are determined from the equations:

$$q_i^* = \frac{-f(\Sigma q_i^*) + c_i'}{f'(\Sigma q_i^*)} \qquad \text{all } i \in E$$

In the following example, we illustrate the types of behaviour that can be analyzed using this approach.

Consider three grain exporting countries, 1,2,3, and let each country i's natural production limit be s_i where the cost of production up to s_i are negligible. Let the demand curve for grain be as shown in Figure 1.

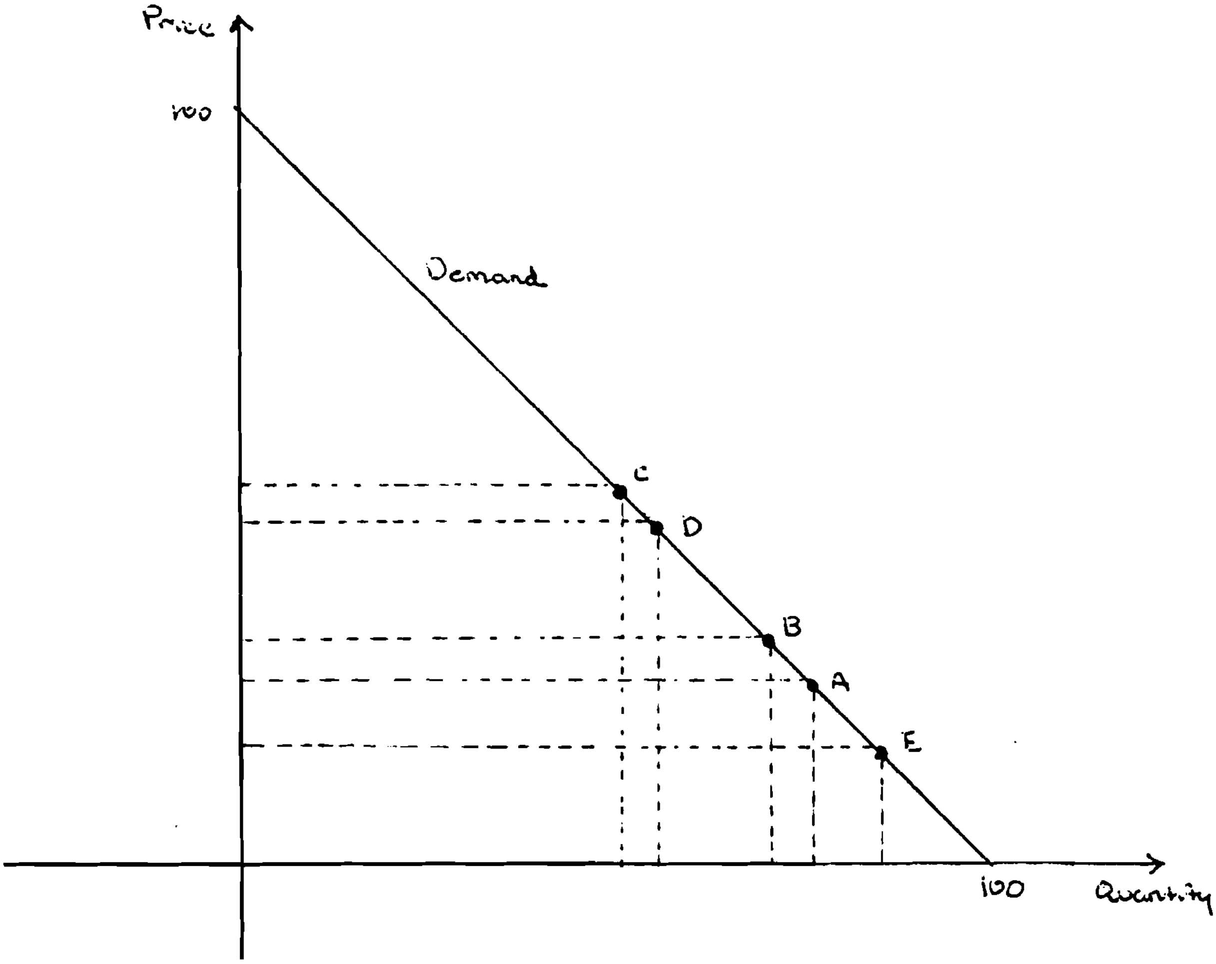

Figure 1

<u>Case A</u>. Production limits (s_1, s_2, s_3) are (60,60,60). Then in equilibrium,

outputs = (25,25,25) , total output = 75
revenues = (625,625,625) , total revenue = 1875

In this case the countries restrict their output to much less than they could naturally produce.

<u>Case B</u>. Production limits (s_1, s_2, s_3) are (10,60,60). Then

outputs = (10,30,30) , total output = 70
revenues = (300,900,900) , total revenue = 2100

In this case, country 1 is operating at full capacity, but both countries 2 and 3 restrict their output.

Case C. Suppose that production limits are as in Case A but the countries form a coalition to monopolize the export market.

outputs = (16 2/3, 16 2/3, 16 2/3) , total output = 50
revenues = (833 1/3, 833 1/3, 833 1/3) , total revenue = 2500

Compared with A, collusion results in higher revenues and much lower food output for consumption by the food-poor countries.

Case D. Let production limits be as in Case B and suppose the two large producers collude to restrict production. Then

outputs = (10, 22 1/2, 22 1/2) , total output = 55
revenues = (450, 1012 1/2, 1012 1/2) , total revenue = 2475

Case E. An important question to ask is whether some dominant producer can act as a "leader" and unilaterally announce a policy that might at first blush seem to be contrary to its self-interest, but that in fact leads to an improvement in its own position as well as in the position of the consuming countries.

Suppose for example that country 1 (e.g. the U.S.) declares unilaterally that it believes in a "liberal" food policy and will produce (out of the goodness of its heart) 50 units. If the other two producers act on the belief that 1 means what it says and they compete, then they will find equilibrium positions as follows:

outputs = (50, 16 2/3, 16 2/3) , total output = 83 1/3
revenues = (833 1/3, 277 7/9, 277 7/9) , total revenue = 1388 8/9

It will be seen that by following this liberal policy, country 1 is actually better off than in Case A, and at the same the consuming nations also benefit.

Even if the other two producers collude to restrict their output the result is still not unfavourable to the consuming nations, total output being the same as in Case A.

outputs = (50, 12 1/2, 12 1/2) , total output = 75

revenues = (1250, 312 1/2, 312 1/2) , total revenue = 1875

The somewhat surprising conclusion emerges that the adoption of a liberal production policy by one country may actually be its best alternative and that it simultaneously benefits the consuming nations.

This analysis shows how, with relatively little data, considerable insight can be gained into strategic possibilities in the market. Other possibilities for trade and production agreements might also be investigated, such as for example the alliance of a particular producer with some subgroup of consumers to the mutual benefit of both.

THE GENERAL EQUILIBRIUM MODEL

The simple oligopoly model involves two strong simplifying assumptions. First, it assumes that there is no strategic behaviour on the consumption side of the world agricultural market; that is, consumers are represented only through an aggregate demand curve. Second, the previous model treats all producers as income-maximizers, rather than taking into account differences in national needs and preferences.

We shall present two less-restricted examples, in a general trade equilibrium context, which illustrate how considerations such as acreage restrictions, food grants, and preferential trade agreements can be studied. For expository and computational simplicity, the examples involve only two commidities and two or three countries. However, it is clear that the observed phenomena can also be found in larger, econometrically-valid models.

Consider two countries (nominally the U.S. and Japan). At the beginning of the trading season, the U.S. has initial stocks of (2,0) of two commodities (nominally, agricultural and non-agricultural goods) and Japan has stocks of (0,1). (The fact that each country has a "corner" on one commodity is not critical to the example, but it simplifies calculations). Assume that each has the same utility function for consumption of the two commodities as shown in Fig.2.

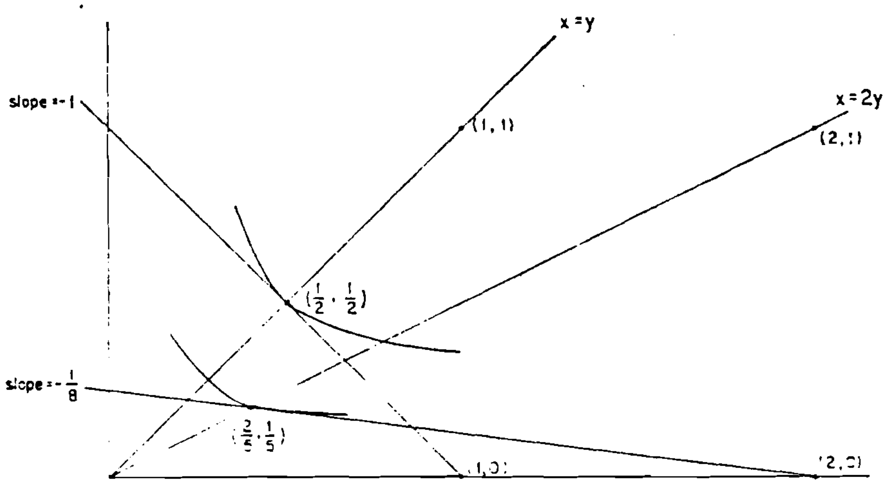

Fig.2.

In this situation it is not difficult to see that the world equilibrium is associated with relative prices of 1:8 and the consumption bundle of the U.S. is (2/5, 1/5) while that of Japan is (8/5, 4/5).

This result is not too surprising; it reflects a situation in which there is an abundant supply of agricultural products. But what if the U.S. intentionally restricts food production (say, by withdrawing certain lands from production)? To be specific, let the U.S. restrict its production so that its initial holding is only (1,0). Now, the exchange equilibrium is at prices of 1:1, with final consumptions of (1/2, 1/2) for each. Observe that the net gain for the U.S. is positive in <u>both</u> commodities.

In a starving world, it may not be politic (or moral) to restrict production solely for personal gain. Could it possibly be to the advantage of the U.S. to freely give some of its food in aid to another nation? If so, what other countries are the natural candidates for this aid?

Consider the U.S. and Japan in the presence of a third country (say, India). Further assume that relative productions of agricultural goods and non-agricultural goods in the three countries are (12,0), (0,10) and (8,0). Further assume that, at consumption levels near those resulting from world trade equilibrium, the respective utility functions are min (4x,3y), min(2x,6y) and min (x,12y). (That is, the complementarity between agricultural and nonagricultural products makes additional units of industrial goods more critical than additional units of food in the U.S; the situation is reversed for India (due to the large national population) and intermediate for Japan. The following (rather surprising) result can then be observed. If the U.S. freely gives some of its food to India (without restrictions on the use of the gift) the resulting world trade equilibrium involves a sufficiently large decrease in the relative price of the industrial good so that the U.S. obtains an increase in utility (over the state of affairs at equilibrium, prior to the food grant). Clearly, the gift also benefits India, while Japan suffers some decrease in utility.

Conditions under which this situation can occur are quite general. If two nations have disparate needs (or preferences) and one has an exportable surplus in a commodity highly desired by the other, then foreign aid in the form of commodity transfers can leave both in a better market position. Examination of this phenomenon in a more elaborate economic context (including, ultimately, the general equilibrium determined by the FAP linking model) could shed light both upon existing trade agreements and upon potential national groupings which might improve the lot of certain developing nations at no cost to their trading partners.

The only data required for this approach, beyond the information already available to FAP, are the relative preferences of the nations for various bundles of commodities. A natural first step towards estimating these preferences might involve aggregating all agricultural products into a single good, and examining stated national priorities relative to agricultural consumption, non-agricultural consumption and the formation of capital stocks (the latter, presumably, to be used for future industrial growth). A procedure for computing equilibrium prices and allocations must also be available; the programs being developed by Keyzer may be of value here.

MULTI-PERIOD MODELS

The previous models have all been static. They refer to decisions in a single period of time. This section is concerned with some problems and decisions which arise when time is taken into account. These new phenomena include:

- trade-offs between consumption and investment in each country (which ultimately involves the trade-off between present and future consumption);
- possibilities of stockpiling to smooth out (or accentuate) patterns of production and prices over time;
- the possibility of temporarily financing imports out of financial resources instead of exports;
- the increased importance of weather variability and political instability as unknown factors leading to disruption of plans;
- the possibility of long term planning instead of myopic year-to-year decision making;
- the difference between long-term and short-term reactions to policies of other countries (e.g. increasing self-sufficiency to avoid dependence on a single supplier, or alternatively specialising where comparative advantage lies whenever stable supplies and markets seem assured).

In this section we outline briefly one general model for handling some of these issues. The next section develops in more detail a relatively simple special case.

Suppose that each country produces a specified amount of output of each product at the "end" of each year. It must decide how much of each output to send to market for export and how much to keep back for domestic consumption. As a result of its market operations it obtains a set of imports which may be used either for further consumption or for investments. Output in the next and future periods will be determined (in part) by the level of this investment. And so the cycle continues. This model is shown diagrammatically in Figure 3.

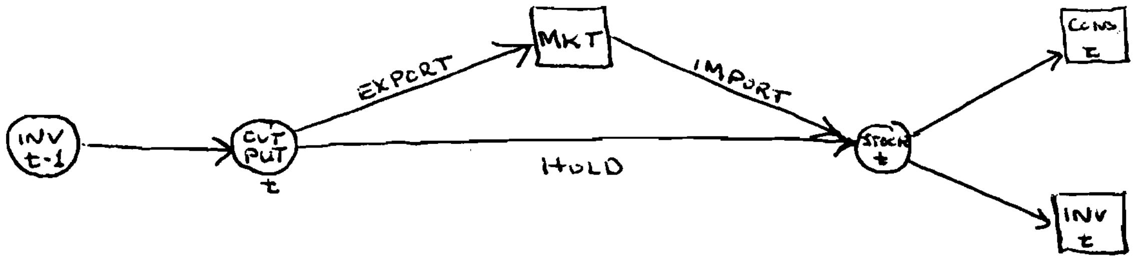

Fig.3 Cycle of Decision for each Country

This model focuses on two kinds of phenomena (1) the trade-off between consumption and investment in each country, and (2) the decision on how much (if at all) to hold off the market in order to raise the price. The operation of the market is modelled as described in the preceding sections. For example, small countries may take the market price as given whereas larger countries may consciously attempt to influence it.

Implementation of the multi-period model would need data and/or assumptions for each country concerning:

(i) production functions of each commodity

(ii) utility functions specifying preferences between consumption of different kinds of foods in different periods of time

(iii) functions relating output or capacity in any period to investments in the previous period.

It would also have to be specified how the market works and how decisions are made. There are basically two possibilities:

(A) Each country is assumed to know the present and future situation and objectives of all other countries, so that an equilibrium solution can (in principle) be calculated embodying optimal decisions for all countries.

(B) Each country makes guesses about the situation and objectives of all other countries, and uses behavioral rules of thumb (possibly looking only one period ahead) to determine its consumption and trade decisions. Essentially this is a simulation approach.

In either case, computational problems would be very severe for large models.

A SPECIFIC MULTI-PERIOD MODEL

In this section we develop a model which tries to represent an idea put forward in conversation with F. Rabar. It seems to be the simplest possible way of analyzing some of the phenomena discussed in the preceding section. In effect, it is a special case of that model. It assumes (1) that production is given exogenously to the model (perhaps indicated by extrapolation of historical data); (2) it is limited to one (agricultural) commodity plus money; (3) all countries except one take the market price as given; (4) the market-leader sets price in anticipation of how the other countries will repond, then has to supply their net requirements (possibly by adjustments to its buffer-stock). This model is shown in Figure 4.

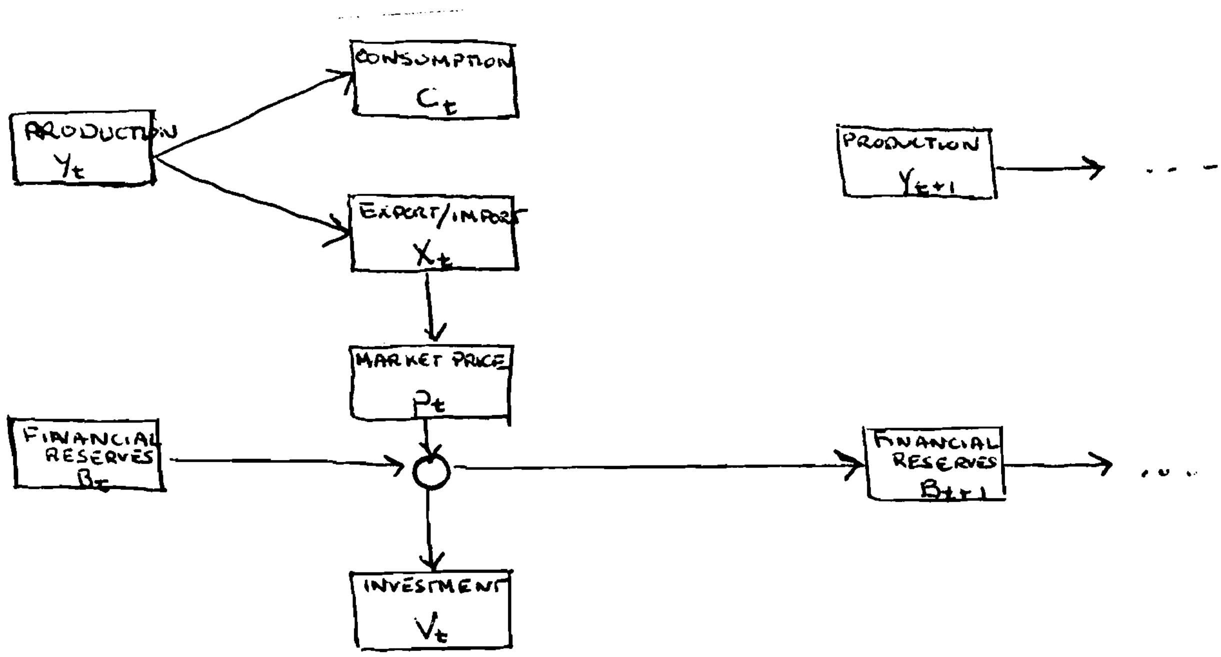

Fig.4. Sequence of Decision for Price-Taking Countries

To model this situation, let

C_t = consumption of food

V_t = investment of funds

X_t = net exports of food (import if negative)

B_t = financial reserves.

The country is assumed to choose levels of these variables to maximise some utility function.

(1) $U(C_1, C_2, \ldots, V_1, V_2, \ldots)$

subject to constraints on distribution of available output

(2) $X_t + C_t = Y_t$

and distribution of funds

(3) $B_t + p_t X_t = V_t + B_{t+1}$

and minimum levels of consumption (e.g. related to subsistence requirements)

(4) $C_t \geq \bar{C}$

investment

(5) $V_t \geq \bar{V}$

and financial reserves (e.g. to avoid bankruptcy, or to stay within scope of world Bank loans etc.)

(6) $B_t \geq \bar{B}$

(These minimum allowable levels could thus vary over time). In the light of these constraints, the utility function could be quite simple, e.g. $U = \sum_t V_t$.

Each of these countries is assumed to know and take as given market price in the current period. We assume that the market-leader is a price-setter. The sequence of decision is thus

- market-leader sets price p_t
- other countries determine net exports X_t
- market-leader meets all market demands taking up variations via buffer-stocks.

The market leader faces a similar problem to the one outlined, with one additional consideration

let R_t = net addition to storage of food

S_t = level of buffer-stock

Then his allocation decision is

$$(7) \quad R_t + X_t + C_t = Y_t$$

Stocks are updated by

$$(8) \quad S_{t+1} = S_t + R_t$$

He may have a constraint on maximum buffer-stocks (e.g. non-negativity)

$$(9) \quad R_t \geq \bar{R} \quad .$$

Finally, the world market must clear, so that

$$(10) \quad \sum_i X_{it} = 0$$

or equivalently

$$(11) \quad X_{It} = - \sum_{i \neq I} X_{it}$$

where subscript i denotes the country and $i = I$ is the market-leader.

This model is evidently of simulation type. Expectations about the current and future behavior of all other players must be fed into the model to determine individually optimal policies.

It is also possible for learning to take place. It does not assume that equilibrium is reached. For example, the market necessarily clears but the market leader may have to export more or less than expected.

In principle, it would be possible to include elements of uncertainty concerning weather, supplies, etc.

The data that this model would require are:

(i) estimates of future supplies for each country

(ii) initial levels of financial reserves plus any exogenous inflows

(iii) utility functions (i.e. objectives)

(iv) minimum acceptable levels of consumption, investment, financial reserves, etc.

(v) expectations concerning (future) market behaviour of other countries (or at least future market price).

This model would be useful chiefly for analyzing the attempts of small countries to escape from the "poverty" trap and the pricing policy of the market leader. It could probably also be adapted to analyze bilateral trade agreements and collusion between countries once the model was running. It would be straightforward to use sensitivity analysis to examine the effects of different assumptions about production, objectives, expectations, etc.

SUMMARY

In general, game theory deals with two types of issues. It attempts to describe, and sometimes prescribe, the behavior of strategic actors in a competitive world. In addition, it studies the gains available through various kinds of cooperative behavior, and methods through which these gains might be shared.

Clearly, both of these aspects of game theory are relevant to the Food and Agriculture Program at IIASA. The establishment of a national agricultural policy is often viewed as a primarily competitive problem, with the goal of increasing the welfare of the nations' citizens. (This goal, of course, involves such diverse matters as industrial growth, price stability, income distribution and agricultural consumption). On the other hand, the formulation of international agreements concerning agricultural assistance, trade preferences, international buffer stocks and the like, involves consideration of the advantages of cooperation.

In the preceding pages, several preliminary suggestions are made concerning approaches to the game theoretic aspects of the world agricultural situation. One model concerns oligopolistic competition between producers of agricultural goods, when their critical decisions are the setting of production (or buffer stock) levels. Examined in this context are the potential gains available to a producer who takes a leadership role in increasing production. Other models are presented in a general equilibrium context. One of them considers the effect of production restrictions on the relative prices of other commodities. Another illustrates the existence of natural trading partnerships, within which an agricultural grant from a large agricultural producer to a developing nation may work to the benefit of both. Finally, a general multi-period planning model is presented, which models national decisions concerning production, investment and consumption, as well as subsequent international marketing decisions. Several preliminary simplifications of this model are also discussed.

This report indicates only a few of the food and agricultural issues to which game theory is relevant; the list of potential applications is far from complete. For example, there is a growing literature on the equitable apportionment of the costs of cooperative agreements. The importance of this literature to the matter of international buffer stock policies is clear. The study of alternative methods of reducing, by cooperative agreements, a nation's exposure to the risk of local climatic variation, and related issues concerning comparative advantage, might also be considered.

As this report has indicated, there are many different kinds of models which lie within the framework of game theory. No one model can hope to answer every question which might be posed. Moreover, there are many aspects of any real-world situation which lie outside the conventional boundaries of game theory. Whatever models are adopted, they can only provide frameworks for organizing different aspects of the available data, and helping to answer specific classes of questions.

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