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An Interactive Simulation Model of the Global Economy

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IIASA Working Paper

WP-77-011

1977

AN INTERACTIVE SIMULATION MODEL OF THE GLOBAL ECONOMY

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September 1977   WP-77-11

Abstract

    Interactive simulation, also known as operational gaming, is a preanalytical tool intended to provide a better intuitive understanding of a given problem situation and to lead through successive approximation to the construction of a realistic analytical model.

    There are two essential features that distinguish interactive simulation from ordinary simulation modeling: Interactive simulation includes the relevant decision-makers among the elements being simulated (by knowledgeable individuals acting as players); and it is dynamic in nature, in that it utilizes the expertise of these players to improve the structure and numerical parameters of the game between plays.

    This paper presents a description of a relatively sophisticated six-person game, called GEM, which attempts to simulate the economic planning and interaction of six world regions.

AN INTERACTIVE SIMULATION MODEL OF THE GLOBAL ECONOMY

Introduction

The model to be described here, which is named 'GEM' (for "Global Economic Model'), is a six-person interactive simulation model (or game), intended to generate intuitive insights into the economic interactions among six world regions over the next fifty years.

Each player is responsible for manipulating the economy of one of these regions. To do so, he has to make resource allocation decisions (between sector inputs, capital investment, investment in R+D, and supplies to consumers and to government); in addition, he may trade commodities with the other five participants and conclude long-term agreements with them concerning trades, loans, investments, and technology transfer.

The six regions, designated by the letters 'S','E','C','O', 'N','D', which are intended to resemble very roughly six real-world regions obtained by aggregation from the ten regions of the Mesarovic/Pestel model*, may be abstractly characterized as follows:

S: A highly developed, centrally planned economy, with substantial energy resources

E: A highly developed market economy, with greatly limited energy resources

C: A developing, centrally planned economy, with substantial energy resources

O: A small developing market economy, with very substantial energy resources

N: A highly developed market economy, with substantial but inadequate energy resources

D: A developing economy, with undeveloped energy resources and a rapidly growing population

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* M. Mesarovic and E. Pestel, "Mankind at the Turning Point", Second Report to the Club of Rome, Dutton, 1974.

The economic structure of each of these regions is highly aggregated and is represented in terms of eight economic sectors.

The GEM game is played over a simulated 50-year period, starting with the present. The 50 years are broken up into ten 5-year scenes, where each scene represents one move cycle in the game.

Purpose

The purpose of such simulation gaming generally is not so much to solve problems directly but to lead to a better intuitive understanding of the problem structure and thereby to help the analyst in the development of models that gradually become more and more appropriate for dealing with the real-world problem situation. Thus a simulation game is preanalytic in nature; it is not intended in itself to be either predictive or decisional. An essential part of the routine of playing a simulation game is a constructive debriefing or review session in which the participants are asked to engage (a) in a self-critique ("what would I do differently if I were to play the game again?") and (b) in a critique of the game ("what numerical inputs, or what structural components, of the game should be altered in order to achieve greater realism?").

As a result of such inquiries, the game is almost invariably changed in some respects between plays. The gaming activity, therefore, should not be viewed as a series of trial runs of a particular simulation model but as a dynamic process in which a more and more realistic conception of the world gradually evolves. A simulation game must have the built-in capability of such potential self-correction.

The particular purpose of GEM is to help acquaint IIASA's staff with the potentialities of simulation gaming as a preanalytical research tool. Thus GEM's primary function is that of a demonstration game. It is for this reason that emphasis has not been placed on obtaining the most precise and up-to-date statistics to serve as input data for the six regions considered in GEM but rather on including in the game model as many important factors descriptive of global economic interactions as are com-

patible with the requirement of keeping the game simple enough
to be easily playable. The absence of precision in the initial
choice of numerical inputs--this defect, if it is felt as such--
can easily be remedied later by substituting more precise data
when these become available. With regard to selecting factors
for inclusion in the model, special attention was paid to IIASA's
particular areas of interest, such as the world food and energy
situations.

Move sequence

The GEM game is played in ten move cycles, called 'scenes',
each simulating 5 years of real time. The record of a particular
play of GEM is a scenario, consisting in a scene-by-scene de-
scription of decisions made by the players as well as of event
occurrences (such as technological breakthroughs or discoveries
of new basic-resource reserves) and of notable changes in trend
values (such as capital investment or labor unrest).

The move structure of each scene is shown in Figure 1 on p.4.

Before explaining in greater detail the elements contained
in Figure 1 and particularly the players' move options, it is
necessary to describe the basic structure of the underlying eco-
nomic model. However, there is one important feature of the game
which deserves to be pointed out first. As is evident from the
indications given in Figure 1, the model contains certain sto-
chastic elements. Some of these reflect influences entirely exo-
genous to the model, such as those controlling the weather and
the growth of population. Others, such as technological break-
throughs or the amount of labor unrest, are endogenous in the
sense that, while they are the result of random (i.e., Monte-
Carlo) decisions, their probabilities of occurrence can be affect-
ed by player actions. The effect of the presence of these sto-
chastic features is that the players have to plan in the face of
some uncertainty as to the results of their decisions. In this
respect the model differs markedly and, it is hoped, in the di-
rection of realism from standard econometric models in which
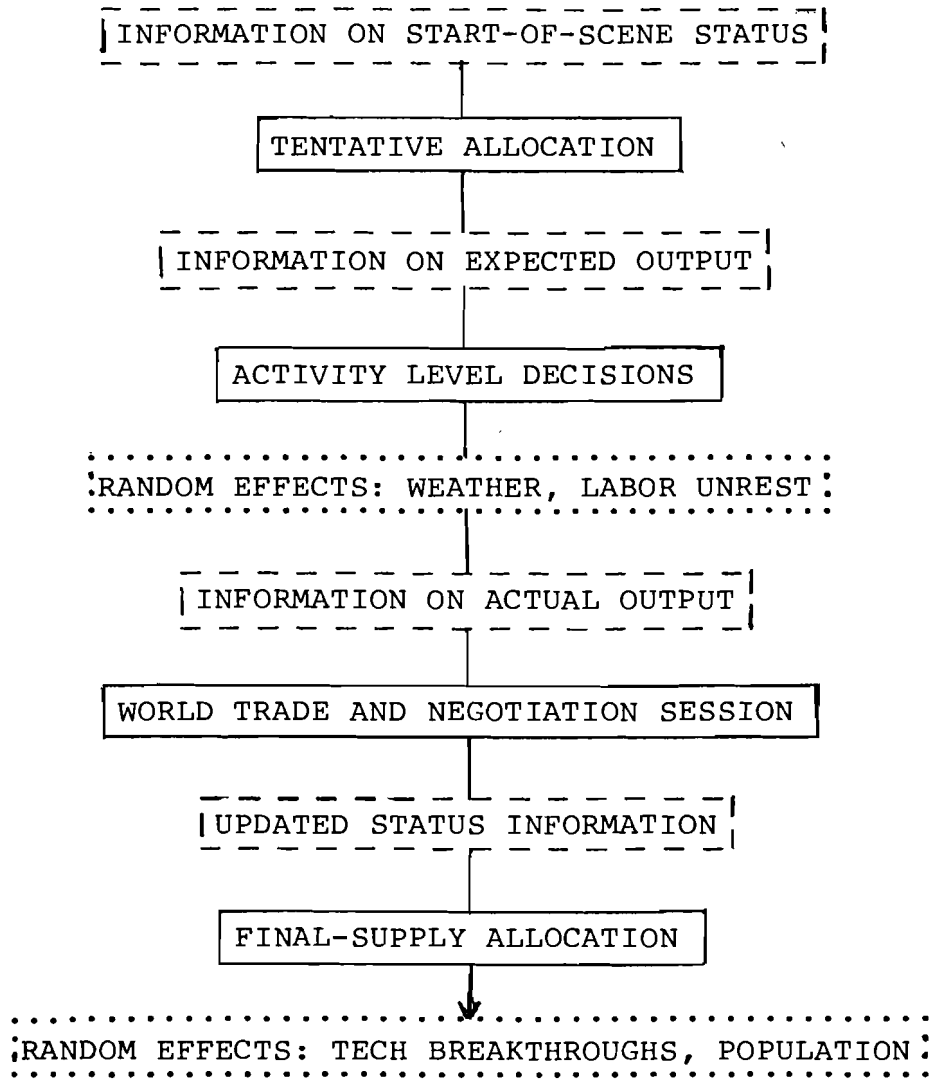economic output is determined solely by input allocations.

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│INFORMATION ON START-OF-SCENE STATUS│
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        │ TENTATIVE ALLOCATION │
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    │ INFORMATION ON EXPECTED OUTPUT│
    └─ ── ── ── ─┬── ── ── ── ──┘
                 │
        ┌────────┴────────────────┐
        │ ACTIVITY LEVEL DECISIONS │
        └────────┬────────────────┘
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   ·················┼··························
   :RANDOM EFFECTS: WEATHER, LABOR UNREST :
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                 │
      ┌─ ── ── ──┴── ── ── ──┐
      │ INFORMATION ON ACTUAL OUTPUT│
      └─ ── ── ──┬── ── ── ──┘
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   ┌─────────────┴───────────────────────┐
   │ WORLD TRADE AND NEGOTIATION SESSION │
   └─────────────┬───────────────────────┘
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      ┌─ ── ── ──┴── ── ── ──┐
      │ UPDATED STATUS INFORMATION│
      └─ ── ── ──┬── ── ── ──┘
                 │
        ┌────────┴────────────┐
        │ FINAL-SUPPLY ALLOCATION │
        └────────┬────────────┘
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 :RANDOM EFFECTS: TECH BREAKTHROUGHS, POPULATION :
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Figure 1: Move Structure of each Scene

Code:

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┌────────────┐
│            │   player moves
└────────────┘

┌─ ── ── ─┐
          ┊   information given to the players
└─ ── ── ─┘

·········
:       :   random effects
·········
```

The economic sectors

The eight economic sectors, in terms of which the economy of each of GEM's six regions is described, are as follows:

1: Mining (other than fuel)
2: Intermediate products
3: Durable goods
4: Consumption goods (other than food)
5: Food
6: Fuels
7: Electric energy
8: Services

The singling out of food as a separate sector and the decision to have energy represented by two sectors (6 and 7) reflect the special importance attached to long-range planning in these areas at IIASA and elsewhere.

To express input/output transactions among the sectors of the economy, it is convenient--and in view of the high degree of aggregation virtually mandatory--to use monetary units in order to be able to add together otherwise incommensurable quantities. Of course, the production process requires certain physical quantities as inputs to obtain a specific physical output, and the monetary value of these inputs and outputs may change as prices fluctuate. A simple way to deal with this situation is to choose a monetary unit and then to define one physical unit of the output of Sector i as that quantity of the i-th commodity whose price, at the outset of the game, is one monetary unit.

As the monetary unit we choose $ 1 B (= one billion dollars).

The operation of the economy is described in terms of an input/output matrix which, for the purposes of GEM plays, can best be presented in the format shown in Figure 2 (p.6). The portion of that display to the left of the double line is the standard format for an input/output matrix. It can be filled in either with technical coefficients, which indicate what physical quantity produced by the sector on the left has to flow into the sector listed above in order to produce one physical unit of

		into Sector								Total req'd in-puts	Net product (=output - req'd inputs)	Old inven-tory	Net im-ports	Avail-able for final supply	Con-sump-tion	Gov-ern-ment	Hard Cap	Soft Cap	New inven-tory
		1	2	3	4	5	6	7	8										
Input from Sector	1																		
	2																		
	3																		
	4																		
	5																		
	6																		
	7																		
	8																		
Cost of inputs																			
Value added																			
Value of output																			

- 6 -

Figure 2

output in that sector; or with actual flow coefficients, expressed in monetary units (which--it should be remembered--are initially equal to physical units), in which case the matrix provides an accounting of actual inputs and outputs and of the resultant surplus available for final supplies.

To change from technical coefficients to monetary flow coefficients it is necessary to multiply the column vector of technical coefficients corresponding to the i-th sector with the activity level of that sector and then to form the inner product with the vector of current prices.

In applications to the real world, an input/output matrix can be interpreted as representing either the rates of flow at a given time or the average flows over a given period (such as a year). In the context of GEM, we shall for game-playing purposes maintain the fiction that the economy of a region operates in two successive stages: In Stage I, the activity levels of the industrial sectors are chosen by the player directing that region, the required inputs for these activity levels are calculated, and the net product (i.e., the total output minus the required intermediate inputs) is determined. This together with existing inventories and net additions derived from imports constitutes the resources available to satisfy final demand. Given this information, the player, in Stage II, decides how to allocate these supplies between consumers, government, capital investment (both 'hard' and 'soft' [see below]), and inventories.

It should be noted that the options available to a player in both Stages I and II are subject to certain obvious constraints. The activity levels chosen in Stage I are constrained by (a) the capacities of the sectors, (b) the total amount of effective labor available, and (c) the requirement that net production plus inventories must be nonnegative. In addition, in the special cases of Sectors 1 and 6, there are limits on known resource deposits, and production may not exceed the extraction of such known deposits. The allocation made in Stage II is subject to the constraints that final supplies must be nonnegative and must add up to the total available for this purpose.

When playing GEM, the options available to a player, as well
as any constraints on his allocations, will be clearly displayed
to him. The constraints will include the absolute ones just enu-
merated as well as "advisory constraints". The latter will in-
form him about (a) the amount of hard-capital investment required
to offset capital depreciation, (b) the level of supplies to con-
sumer households (food and other commodities) necessary to pre-
vent deaths from starvation and civil unrest, and (c) the level
of supplies to government necessary to prevent deterioration of
government services (see below).

While in standard econometric models the output of the econo-
mic sectors is completely determined once their activity levels
have been set (provided, of course, the proper feasibility con-
straints have been met), this is not so in GEM, since there are
two built-in random elements affecting the output: One is the
uncertainty of the amount of labor unrest, which affects the size
of the effective labor force (see the following section) and
thereby indirectly the output of each sector; the other is the
regional harvest conditions (weather, crop and cattle diseases,
pests, etc.), which are simulated as follows: for each region and
each scene, a random deviate δ is drawn from a normal distribu-
tion with quartiles at ±.05, and the nominal food output for that
region and scene is then multiplied by $1 + \delta$.

Population and labor

Population, and labor in particular, are measured in units
of one million persons.

For each region, a fixed population growth rate has been as-
sumed:

Region	S	E	C	O	N	D
Population growth rate per scene (in percent)	4	2.5	7.5	10	4	10

The population, P, if provided adequately with food, will thus
grow exponentially, except that the increment, ΔP, from Scene j
to Scene j+1 will be replaced by $\Delta P + \delta$, where δ is a random de-
viate drawn from a normal distribution with quartiles at $\pm\frac{1}{4}\Delta P$.

If the annual food supply (measured in monetary units) per population unit is f, then the predicted population declines from P to

$$P' = \frac{f^2}{.0003 + f^2} \, P.$$

(For example, if the annual per-capita food supply is 100 dollars' worth, then the food supply per population unit is valued at

$$\frac{100 \times 10^6}{10^9} \, ,$$

or 0.1 monetary units. Hence $f = .1$ and $P' = .971 \, P$. In other words, at this level of food supply, the population, over a five-year scene, will be reduced by about 3%.)

The total labor force, TLF, for simplicity, is set equal to $.45 \, P$ for all regions.

The total labor force may be reduced in its effectiveness by labor unrest. If the amount of labor unrest is u, where $0 \leq u \leq 1$, then the effective labor force is

$$ELF = \frac{1}{1 + 4u^2} \, TLF.$$

(Thus, in the worst case, when $u = 1$, ELF is only 20% of TLF.)

The quantity u is a function of random fluctuations as well as of the proportionate scene-by-scene rate of increase, d, in per-capita supplies to households. If $Cons_i$ is the personal consumption in Scene i (= the monetary value of supplies allocated to households), Pop_i the population in Scene i, and $Q_i = Cons_i/Pop_i$, then

$$d = \frac{Q_{i+1} - Q_i}{Q_i} \, .$$

The allocation of supplies to households (described by a vector H) is a little more complex than that of government supplies. First of all, a food allotment, H_5, is chosen. The remaining components of H essentially are to be in proportion to a given profile, except that there is some built-in flexibility, in that up to 20% of each of the components H_3, H_4, H_8 may be substituted

for by the others, and similarly up to 20% of the components H_6 and H_7 may be substituted for by the other.

For u to remain constant, d has to equal some minimal rate of increments in total per-capita supplies to households, which we shall here simply assume to be 10% per scene, or d = .1. If u is the labor unrest in one scene and u' that in the next scene, we shall set

$$u' = f(u,d),$$

where, in addition to f(u,.1) = u, we shall assume that f(u,-.5) = 1 and f(u,1) = 0 (that is, halving per-capita supplies will cause labor unrest to rise to its maximal value of 1, whereas doubling supplies will quell such unrest altogether). A relatively simple such function, which will be adopted here, is

$$u' = \frac{4(1 - d)u}{(1 - 10d)u + 6d + 3}.$$

Superimposed upon this function we assume a random distribution, as follows: let δ be a random deviate drawn from a normal distribution with quartiles at ±.05; then replace u' by

$$\min[1, \max(0, u' + \delta)].$$

(This simply adds δ to u', except that cut-off points are introduced at 0 and 1.)

A fraction s of the effective labor force is skilled, the remainder, 1 - s, unskilled. The quantity $\sqrt{s}$ is called the 'labor productivity multiplier', and the 'available skilled-labor equivalent' is defined as follows:

$$SLE = \sqrt{s} \cdot ELF.$$

Note that if s = 0 then SLE = 0 and if s = 1 then SLE = ELF, and that the marginal effect of an increased skill fraction is a decreasing function. Skilled-labor equivalents are treated as being freely interchangeable.

The skill level of the labor force is assumed to decline 10% per scene unless this trend is countered by governmental educational efforts, as evidenced by the government's efficiency level (see next section). Note that labor productivity, which may be defined as GNP/TLF, is equal to $\sqrt{s} \cdot GNP / (1+4u^2) SLE.$

Government

The government requires final supplies from Sectors 3,4,6,7,8 in fixed proportion. The activity level of this supply vector will determine government efficiency, g, which in turn will affect (a) the skill level of the labor force, (b) the capital coefficients (both hard- and soft-capital), (c) the rates of inventory depreciation, and (d) the quality of information on commodity quantities available to the player for planning purposes.

We assume that g is measured on a scale from 0 to 1 and that it is a function solely of the per-capita activity level, x, of the vector specifying supplies to the government. Let x = a be that level of per-capita supplies at which the government operates at efficiency g = .9. Then we set

$$g = \frac{9x^2}{a^2 + 9x^2} ,$$

which has the effect that doubling the supplies to government raises government efficiency from .9 to .97, whereas halving them lowers it from .9 to .69. (The quantity a as well as the components of the governmental supply vector will be prescribed individually for each region.)

We next turn to the determination of the quantities affected by the level g of government efficiency.

Skill level: The skill level, s, as stated before, will deteriorate at a rate of 10% per scene if no educational provisions are made. The amount of such education is assumed to be implicit in the efficiency level of the government. To maintain a skill level s (that is, just to counteract the 10% deterioration), it is assumed that an efficiency g = s is required. Below that, s will decline; above it, s will increase. The formula to be used is as follows:

$$s_{i+1} = .9s_i + .1g_{i+1},$$

where the indices i and i+1 refer to Scenes i and i+1. For $g_{i+1} = 0$ this formula yields $s_{i+1} = .9s_i$; for $g_{i+1} = s_i$ it yields $s_{i+1} = s_i$; and for $g_{i+1} = 1$ it yields $s_{i+1} = .9s_i + .1$ [$= s_i + .1(1 - s_i)$] (in other words, maximal governmental efficiency moves the value of s from s_i one tenth of the way toward its theoretical maximum value of 1).

Capital coefficients: The vector of hard-capital coefficients, which specifies what capital inputs are required to increase the capacity of a sector by one unit, suffers a proportional increase if government is inefficient. Specifically, if under ideal conditions (g = 1) a vector of capital coefficients is C, it is replaced by

$$C / (2g - g^2)$$

if the efficiency is g. [Note that $0 \leq 2g - g^2 \leq 1$ since $2g - g^2 = 1 - (1 - g)^2$.] Exactly the same rule applies in the case of a vector of soft-capital coefficients (which specifies what capital inputs are required to raise the probability of a technological breakthrough from p to $\frac{p+1}{2}$).

Inventory depreciation: Inventories in Sectors 2 to 5, in the ideal case of g = 1, are assumed to deteriorate at the following rates per scene:

Sector	2,3,4	5
Depreciation	.10	.25

(The depreciation rate in Sectors 1 and 6 is 0, and the term is not applicable to Sectors 7 and 8.) In general, these depreciation rates are multiplied by 2 - g.

Quality of information: The information received by a player during Stage I of operating the economy of his region is to the effect of what resources he may expect to have available to satisfy final demand, based on his tentative choice of activity levels, and what resources he has in fact available for this purpose, following his definite choice of activity levels. In order to simulate the heightened uncertainty in any national economic planning process that has its cause in governmental inefficiency, the pieces of information just mentioned will be modified slightly. In fact, if the final output of a sector is x, the information given to the player will be x + δ, where δ is a random deviate drawn from a normal distribution with quartiles at $\pm.2(1 - g)x$, where g is the governmental efficiency. Note that this deviation is 0 for g = 1 and 20% for g = 0.

In applying this rule, the same deviate will be used for the same output component, regardless of whether this information per-

tains to a tentative (expected) output or the output resulting from the player's definite choice of activity levels. (This is to make it impossible for him to increase the accuracy of his information by repeated sampling.)

Capital investment

There are two kinds of capital investment, denoted as 'hard' and 'soft'.

Hard-capital investment consists in the expansion of production facilities, using existing technologies. It requires as inputs durable goods (Sector 3) and services (Sector 8). The capital coefficients, c_3 and c_8, which specify the amounts of these inputs required to expand capacity by one unit (one unit being the amount of capacity needed to produce one unit of output), of course depend on the sector which is being expanded and on the available technology; however, it will be assumed throughout that $c_8 = \frac{1}{4} c_3$. (If several technologies are available, it will be assumed that expansion utilizes the most recently acquired technology, unless the contrary is specified by the player.) All production capacity is assumed to depreciate at the rate of 25% per scene.

Soft-capital investment represents an R+D effort; it consists in promoting certain technological breakthroughs (see below) by attempting to enhance their probability of occurrence. Soft-capital investment, too, requires inputs from Sectors 3 and 8 only. The soft-capital coefficients, d_3 and d_8, specify the amounts of these inputs required to enhance the corresponding probability by one unit, where the meaning of a 'unit enhancement' will be explained presently. In this case, too, for simplicity, a fixed ratio between d_3 and d_8 will be stipulated; in fact, we shall set $d_8 = d_3$, with the value of d_3 depending on the breakthrough sought.

The details of handling technological advances and their consequences will be the subject of the following two sections of this paper.

Technological breakthroughs

It will be assumed that each sector's production process is capable, in principle, of technical improvement resulting in a more economical method of production. Such an improvement will be the consequence of a technological breakthrough, which is treated as an event having, for each scene, a certain probability of occurrence that can be estimated and also can be influenced by investment in appropriate R+D ('soft-capital investment').

A technological breakthrough in Sector i causes the technical-coefficient vector for Sector i,

$$(x_{1i}, x_{2i}, \ldots, x_{8i}, L_i)$$

(where 'L' stands for 'labor') to be changed to a different vector:

$$(x'_{1i}, x'_{2i}, \ldots, x'_{8i}, L'_i).$$

Also, while the resource costs of a capacity unit for Sector i had been, say, $c_3, \frac{1}{4}c_3$ (for Commodities 3 and 8 respectively), the new resource costs will be some other quantities $c'_3, \frac{1}{4}c'_3$. Once a technological breakthrough in a sector has occurred, the player's further investment in capital-stock expansion in that sector, in-cluding the replacement of capacity depreciation, will—as stated before—automatically be assumed to utilize the most recently ac-quired technology (unless the contrary is specified). As a re-sult, the sector will operate in a mixed mode, using partly the obsolete and partly the novel technology.

Specifically, the potential technological breakthroughs in-cluded in GEM are these: First of all, for each sector S_i (i = 1,2,...,8), there are what may be considered normal technical-improvement breakthroughs, which for simplicity we standardize as follows:

TB_i = a technological improvement in Sector i, having the effect of reducing the last four technical coefficients from $x_{6i}, x_{7i}, x_{8i}, L_i$ to 90% of their values, that is, to $.9x_{6i}, .9x_{7i}, .9x_{8i}, .9L_i$.

Each of these technological breakthroughs may occur repeatedly (but only once in each scene). Aside from these eight, there are six other potential events, of which three are also production-

process breakthroughs (but going beyond normal technical improvements), and the remaining two are other developments improving the state of the economy. (The index, in each case, refers to the industrial sector to which the breakthrough pertains:)

TB_1' = the detection of hitherto unknown mineral reserves within the region, increasing the amount of known reserves by $100(r+1)$ units, where r is a random integer drawn from a uniform distribution over the set from 0 to 9;

TB_5' = the feasibility of large-scale nonagricultural food production;

TB_5'' = the feasibility of controlling the weather, resulting in an improvement in average harvest conditions that cause the harvest to be increased by 1% in the following scene, by 2% in the scene thereafter, and so on, over what it would have been otherwise;

TB_6' = the detection of hitherto unknown fuel reserves within the region, increasing the amount of known reserves by $100(r+1)$ units, where r is a random integer drawn from a uniform distribution over the set from 0 to 9;

TB_7' = the feasibility of producing electric energy from solar power plants;

TB_7'' = the feasibility of producing electric energy from fusion power plants.

Of these, TB_5', TB_7', and TB_7'' are production innovations. None of these are repeatable; however, any normal improvement in Sectors 5 or 7 (i.e., the occurrence of TB_5 or TB_7) is considered to apply also to these new technologies, reducing their last four technical coefficients by 10%. Of the other three events, TB_1' and TB_6' are repeatable while TB_5'' is not.

Forecasts and enhancement of technological breakthroughs

Plays of GEM will be based on probabilistic forecasts regarding the occurrence of technological breakthroughs. For the time being, it will simply be assumed that, in the highly developed regions S, E, and N, the basic probability of occurrence per scene will be .10 for each TB_i, where 'basic' refers to the case where there is no additional enhancement through soft-capital investment (see below). (These probability assumptions, like many other GEM parameters, can easily be modified later if and when information is available that would lead to more realistic values.) For the remaining breakthroughs, the scene probabilities will also be assumed to be constant, as follows:

TB_1'	TB_5'	TB_5''	TB_6'	TB_7'	TB_7''
.05	.02	.02	.05	.02	.01

Note that for the nonrepeatable events (TB_5', TB_5'', TB_7', TB_7'') these scene probabilities are conditional on the event not having occurred in an earlier scene; once they have occurred, their subsequent scene probabilities will be zero.

In the developing regions C and O, all of the above probabilities are replaced by $\frac{1}{2}$ their values, and in the sixth region, D, they are replaced by $\frac{1}{4}$ their values.

If the manager of a region wishes to enhance the probability of a technological breakthrough through soft-capital investment, he can do so by allocating equal quantities of durable goods (Sector 3) and services (Sector 8) to it.

If the probability for the next scene was p, raising it halfway toward its theoretical maximum value of 1, that is replacing

$$p \quad \text{by} \quad p + \frac{1}{2}(1-p),$$

will be referred to as a 'unit enhancement'. The cost (in resources from Sectors 3 and 8) of achieving a unit enhancement will be stated as

$$d_3 = d_8 = c,$$

where the value of c depends on the particular breakthrough being promoted.

If k·c is allocated to enhancing the probability of the break-through (where k > 0), the resulting enhancement will consist in replacing

$$p \quad by \quad p + [1 - (\tfrac{1}{2})^k](1 - p).$$

Here k is called the 'degree of enhancement'.

If, as a result of an enhancement, the breakthrough still does not occur in the next scene, the effort is not assumed totally wasted but, as in the real world, some of the effort (in the case of GEM, one half) carries over to the following scene. That is, if k·c was invested in Scene i, the effect in Scene i+2 will be as though $\tfrac{1}{2}$k·c had been invested in Scene i+1; similarly the effect in Scene i+3 will be as though $\tfrac{1}{4}$k·c had been invested in Scene i+2; and so on.

Note that technological breakthroughs are region-specific. However, once a breakthrough has taken place somewhere, all scene probabilities related to that breakthrough in other regions are enhanced by one unit in subsequent scenes (that is, p is raised to $\tfrac{p+1}{2}$). Moreover, a new technology can be transferred to another region if the donor contributes the service portion of the required capital investment during the first scene when such investment is undertaken. The minimal level of investment, for this purpose, is that required for one capacity unit.

Cross impacts

Technological advances do not occur in complete isolation from one another. That is to say, the occurrence of one may influence the subsequent probability of occurrence of others. These mutual effects are referred to as 'cross impacts'. For instance, if there are two rival breakthroughs, such as TB_5 and TB_5', a player, once he has achieved one of these, may well decide to allocate fewer resources to the other, thereby reducing its probability of occurrence. Conversely, one breakthrough may technically facili-tate another and thus raise its probability of occurrence; for in-stance, an advance in production technology in Sector 3 (i.e., TB_3) may thus trigger a similar advance in Sector 4 (i.e., TB_4).

The first of these impacts, that is, the reduction in probability of rival technologies, is taken care of in GEM via the players' own actions. The other, the mutual enhancement of technological progress, needs to be inserted in the mathematical model. We shall not try to be sophisticated about this but merely reflect this effect in a very simplistic manner.

It will be assumed that these mutually enhancing impacts occur between

(a) TB_1 and TB_6;

(b) TB_2, TB_3, and TB_4;

(c) TB_1' and TB_6'.

Whenever one of these occurs in a region, it will be assumed that the other (or others, in Case (b)) will be enhanced by one unit. That is, the effect, say, on TB_6 will be the same if, in the preceding scene, TB_1 occurred in the same region or if TB_6 occurred in some other region.

Since all of the affected events are potentially repeatable, we have, for the present purpose, to distinguish between their first, second, and so on, occurrence. It has to be understood that the impacts described above refer to the effect of the i-th occurrence on the i-th occurrence.

World trade

There are six tradable commodities, namely, those produced by Sectors 1 through 6. Electricity (Sector 7) and services (Sector 8) are not considered tradable, but some services may be transferred from one region to another as part of a technology transfer arrangement (see p.17).

During each scene there will be one international meeting among the players, which consists of a formal trading session as well as informal negotiations. The latter, which may take place both before and after the formal session, may result in bilateral agreements concerning loans, investments, technology transfer, and future trading arrangements. Forms are provided for recording such agreements. The purpose of these forms is to make sure that there is no misunderstanding of what has been agreed to, but the rules of the game imply no enforcement of any such contracts.
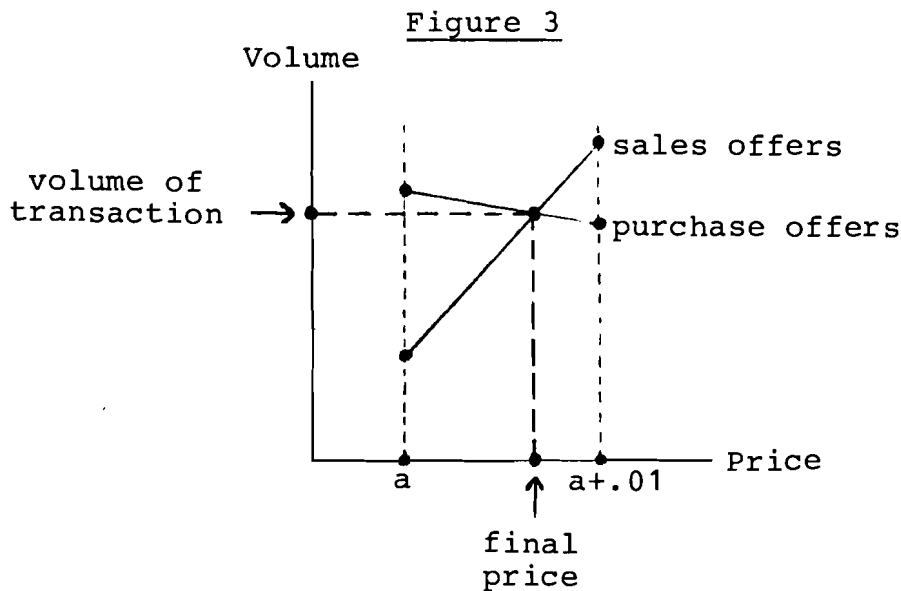
To facilitate sales during the formal trading session, each player is provided with a small amount of international currency (generally equalling one tenth of his region's initial GNP). It is expected that the players will balance their imports and exports sufficiently well to stay within these cash flow limitations. If they cannot do so, they will have to rely on negotiated loans or gifts from the other players.

A GEM scene covers 5 years; but since it is customary to state GNP and other economic indicators in annual figures, it will be more convenient for the players if scene statistics in GEM, such as sectoral inputs and production, GNP, final supplies, and trades are expressed in annual amounts. Thus, if Region X is said to have a GNP of $ 800B in Scene i, this should be interpreted as meaning that the average GNP during the 5 years comprised by Scene i is $ 800B. Similarly, a trade agreement in a given scene resulting, say, in the sale of 20 units of durable goods from X to Y is interpreted as a sale of 20 such units in each of the 5 years of that scene.

All trades involve an expenditure in services (reflecting the cost of transportation, finance, etc.). In GEM both buyer and seller will be assessed .025 units of services for each unit of commodities traded.

The formal trading session proceeds as follows: For each commodity (1 through 6), the latest world price is posted (at the start of the game it is 1.00 for each commodity). There is a playing board with six sections, one for each commodity. Each player is assigned a color and is given a supply of circular and square markers in his color. Circles are used to represent offers of sale, squares to represent offers of purchase. To indicate how many units of each commodity each player wishes to sell or buy at the posted price, he places a corresponding number of circular or square markers in the appropriate section of the playing board. (For convenience, half-size markers are also made available to represent half-units, but finer subdivisions are not permitted.) If the total number of circles and squares in a section happen to be equal, the sales are completed at the posted price. If supplies

exceed, or fall short of, demands, the price is lowered or raised, respectively, by .01 and rounded down or up to the nearest multiple of .01, and the players are given an opportunity to adjust their offers. If, in this process, an exact balance is achieved, the sales for the corresponding commodity are considered completed at the new price. Otherwise the process is terminated as soon as a switch from an excess supply to an excess demand, or conversely, is observed, in which case the sales volume and the price are determined by linear interpolation between the positions just prior to and just after the switch (see Figure 3). (Credit for the basic idea of this procedure should be given to Robert Bickner.)

Figure 3

Dummy players

Provision has been made to carry out plays of GEM when there are fewer than six players by automating the actions pertaining to one or more of the regions. This is done by prescribing specific policies to be followed by such "dummy players", as described below.

The advantage of this provision is not only to accommodate groups of fewer than six participants, but also to offer the important possibility of systematically exploring the relative value of preset policies by repeatedly exposing them to the vicissitudes of random events and interventions by opposing players.

For this purpose we define the choice of a 'policy' as consisting in the assignment of importance ratings, as follows:

(a) $\alpha_1, \alpha_2, \ldots, \alpha_8$ to the 8 industrial sectors, and

(b) $\beta_1, \beta_2, \beta_3$ to the 3 final-demand sectors: households, government, and capital investment.

These ratings are to be integers from 1 to 4, where

> '1' indicates 'no importance',
>
> '2' indicates 'slight importance',
>
> '3' indicates 'moderate importance', and
>
> '4' indicates 'great importance'.

We further define a 'maintenance operation' as consisting in running the economy in such a way that the quantities

> f (= per-capita food supply),
>
> g (= government efficiency), and
>
> the capacities of the industrial sectors

remain at their previous levels, and that the level of supplies to households rise at the rate of 10% per scene (which prevents labor unrest from increasing).

A 'strategy' for implementing a given policy has to specify what actions, normally decided on by a player, are to be taken with regard to the choice of activity levels, trade with other regions, and the allocation of final supplies. These specifications are as follows:

Choice of activity levels:

(a) Let y be the final-demand vector that has to be met to achieve a maintenance operation; then

$$x = (I - A)^{-1}y$$

is the corresponding activity-level vector.

(b) If any component of x exceeds the available capacity, that component should be reduced accordingly.

(c) If the vector thus reduced still cannot be implemented because of excessive demands on resource inventories or labor, then the components x_i of x are reduced by amounts proportional to $5 - \alpha_i$ until the existing resource and labor constraints are satisfied.

(d) If implementation of the activity vector x would leave some excess resources as well as labor, then the components x_i of x are increased, within capacity limitations, by amounts proportional to α_i until at least one of the excess resources or the excess labor are used up.

Trade with other regions:

(a) No contracts are made.

(b) The quantities of commodities that the dummy region would want to supply to, or demand from, the world market are determined as follows. Let

I = current inventory (i.e., the inventory at the beginning of the scene, plus net output),

M = vector of supplies required to carry out the maintenance operation,

D = resources deficit, defined as the currently observed shortage in input resources from sectors that are running at a deficit (i.e., are not producing as much as is required for intermediate output),

F = vector composed of

β_1 units of household supplies,

β_2 units of government supplies, and

β_3 units of capital investment.

Here, in allocating the components H_i of the household supply vector, we make use of the flexibility stipulated earlier:

H_3 is replaced by $H_3' = H_3 - \min(.2H_3, .2H_8)$,

H_4 is replaced by $H_4' = H_4 - \min(.2H_4, \max[0, .2(H_8-H_3)])$,

H_6 is replaced by $H_6' = H_6 - \min(.2H_6, .2H_7)$,

H_7 is replaced by $H_7' = H_7 + \min(.2H_6, .2H_7)$,

H_8 is replaced by

$$H_8' = H_8 + \min(.2H_3, .2H_8) + \min(.2H_4, \max[0, .2(H_8-H_3)]).$$

We now form the vector

$$Y = I - M - D - \gamma \cdot F,$$

where γ is a parameter yet to be chosen. The positive components of Y will represent the surplusses, the negative components the deficits associated with providing final supplies at a level γ above that required for maintenance. Now choose for γ the largest value for which

(i) $Y_7 \geq 0$ and $Y_8 \geq 0$, and

(ii) $V(Y_1)+V(Y_2)+\ldots+V(Y_6) = 0$, where $V(Y_i)$ is
        the value of Y_i at its current world price.

The positive components among $Y_1, Y_2, \ldots, Y_6$ of the re-
sulting vector Y will be the quantities desired to be
supplied to the world market, while the negative com-
ponents among $Y_1, Y_2, \ldots, Y_6$ represent the quantities
desired to be purchased from the world market.

(c) The quantities of commodities to be offered to, or de-
manded from, the world market, as determined under (b),
apply to current world prices. As these prices get
changed during the trading session, the quantities
offered or demanded should be changed by percentages
equal to 10 times the percentage changes in price (the
change being rounded up to the nearest $\frac{1}{2}$ unit). The
sign of the change is equal to that of the price change
in the case of sales offers, opposite in the case of
purchase demands. (For example, if the current world
price of a commodity was 1.05 and is changed to 1.06
-- an increase of .95% -- then an offer to sell, say,
20 units of that commodity would be increased by 9.5%
to 21.9, or rounded up to 22.)

Allocation of final supplies:

To satisfy final demand, the following supply dispositions
are made:

(a) D is set aside as part of next scene's starting inven-
tory.

(b) M is used to supply the maintenance operation.

(c) The largest value of γ is chosen for which
$$M + D + \gamma \cdot F \leq I,$$
where I is the new inventory (after completion of trades),
and $\gamma \cdot F$ is used to supply $\gamma \beta_1$ units of additional house-
hold supplies, $\gamma \beta_2$ units of additional government supplies,
and $\gamma \beta_3$ units of capital investment.

Here, of each unit of capital investment, 90% is to
go into hard- and 10% into soft-capital investment.
Thus the distribution of Commodities 3 and 8 alloca-
ted to capital investment is as follows:
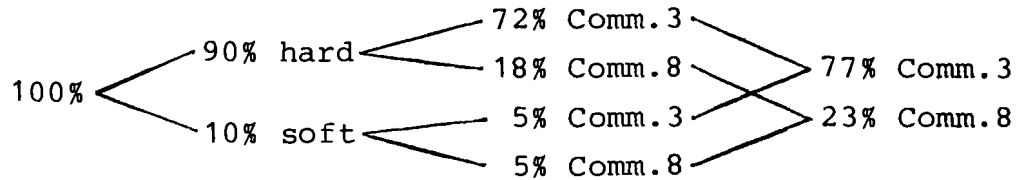
(d) The hard-capital investment portion is distributed
over Sectors 1 to 8 in the ratio $\alpha_1 : \alpha_2 : \ldots : \alpha_8$.

(e) The soft-capital investment portion is devoted to pro-
moting a breakthrough (or breakthroughs) in the sector
(or sectors) S_i for which $\alpha_i = \max(\alpha_1, \ldots, \alpha_8)$, to
be equally split when there are several candidates.

It should be mentioned that the above provisions for automating
the operation of a GEM region can also be invoked if a player,
after participation in several scene rounds, wishes to relinquish
further active participation in favor of merely setting a policy
and turning over the further management of his region to automatic
control.