STRATEGEM-2: A Microcomputer Simulation Game of the Kondratiev Cycle

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ABOUT THE STRATEGEM SERIES

The STRATEGEM series has been developed jointly at the International Institute for Applied Systems Analysis, Laxenburg, Austria; the Resource Policy Center at Dartmouth College; and the System Dynamics Group at MIT. The project focuses on techniques for marrying computer simulation models with management training games. One phase of this project is a program of game development that draws on three specific components:

- Sophisticated (though not necessarily large) simulation models of specific systems that are relevant to senior managers in the corporate and public sectors,

- Inexpensive, portable microcomputers that can operate the models on the home ground of potential clients, and

- playing boards with associated pieces that offer players an accounting and communication aid while they are playing the game.

The games in this series are all called STRATEGEMS (Strategic Games for Educating Managers). Each game in the series is programmed in the BASIC computer language so that it can be implemented on an extremely wide variety of small microcomputers. Each game kit is available from IIASA ready to play, and each is documented sufficiently well that users may customize them.

Information about the games that are so far available in the series may be obtained from Dennis Meadows, Resource Policy Center, Box 8000, Dartmouth College, Hanover, NH 03755 USA. For copies of or information on STRATEGEM-2 (described in this paper) contact John Sterman, System Dynamics Group, E40-294, MIT, Cambridge, MA 02139 USA.
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ABSTRACT

The economic crisis of the 1980s has revived interest in the economic long wave or Kondratiev cycle, a cycle of prosperity and depression averaging about 50 years. Since 1975 the System Dynamics National Model has provided an increasingly rich theory of the long wave. The theory emerging from the National Model explains the long wave as the endogenous result of decisionmaking by individuals, corporations, and government. The advantages of the National Model are its wide boundary and the rich detail in which economic behavior is represented. However, the complexity of the model makes it difficult to explain the dynamics underlying the long wave.

This paper describes a simulation game which demonstrates how long waves can arise. The game focuses on the role of capital investment in the genesis of the long wave. Players manage the capital-producing sector of the economy, and strive to match the capacity to produce capital with the demand for capital. The game vividly shows how the investment and production policies pursued by individual firms, though rational from the point of view of the individual actors, interact in the context of the whole system to produce "irrational" behavior—periodic over- and under-expansion of the economy.

The paper describes the structure and rules of the game, including protocols for operating the game. It has been played by undergraduates, professional economists, and senior executives in industry. In virtually all cases a small step in the demand for capital results in large amplitude cycles with periods between 30 and 70 years. The behavior closely matches that of the simple long-wave model. The long wave arises despite the fact that players have perfect information and full knowledge of the system structure.

The game can be played manually or on personal computers. The paper includes virtually all the materials needed to play the game, in either the board version or the personal computer version. The game board, record sheet, and a listing of the computer program (in BASIC and suitable for IBM PCs) are included.
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1. HISTORY AND PURPOSE OF STRATEGEM-2

The economic malaise of the 1980s has revived interest in the economic long wave or Kondratiev Cycle, a cycle of prosperity and depression averaging about fifty years (Kondratiev 1935, 1984). Most students of the subject believe that the depression periods in the 1830s, 1870-90s, and 1930s were Kondratiev downturns. They suggest the difficulties of the 1970s and 1980s are symptoms of the current downturn in the long wave. A substantial amount of evidence now supports the view that the long wave is indeed a real phenomenon (Bianchi et al. 1983; Freeman 1983; Freeman et al. 1982; Senge 1982; Sterman 1984a; Van Duijn 1983). The economics profession as a whole, however, has remained skeptical (Mansfield 1983; Rosenberg and Frischtak 1983). In part the skepticism arises from the lack of a well-developed theory to explain how such long fluctuations could arise.

Since 1975 the System Dynamics National Model, a large computer simulation model developed at MIT, has provided an increasingly rich theory of the long wave (Forrester 1976, 1977, 1979, 1981; Graham and Senge 1980; Sterman 1984a, 1984b). The theory emerging from the National Model explains the long wave as the endogenous result of decisionmaking by individuals, corporations, and government. The theory relates capital investment, employment, workforce participation, wages, inflation, debt, interest rates, monetary and fiscal policy, innovation, productivity, and even political values. The advantages of the National Model are its wide boundary and the rich detail in which economic behavior is represented. However, the complexity of the model makes it difficult to explain the dynamics underlying the long wave in a simple and convincing manner.
A simplified model of the long wave was developed to communicate the essence of the long wave (Sterman 1984b). The simplified model contains less than thirty equations, compared to about 1600 for the full National Model, and it can be simulated on a variety of personal computers. It has been used successfully in the classroom and as the basis for student projects. The simple model focuses on the role of capital investment in the genesis of the long wave. The model shows how the investment and production policies pursued by individual firms, though rational from the point of view of the individual actors, interact in the context of the whole system to produce dysfunctional behavior—periodic over- and under-expansion of the economy.

However, even the simple model is too complex to convey the essence of the theory to people who have no training in mathematical modeling. Needed is an even simpler and more immediate way to demonstrate how long economic fluctuations can arise. This paper describes a simulation game which fulfills that purpose.

No modeling or quantitative skills (beyond arithmetic) are required to play STRATEGEM-2. The game can be played in about two hours and by individuals or teams. Like the simple model, the game illustrates how the investment and production policies of individual firms can lead to over- and under-expansion of investment and production capacity for the economy as a whole. The game, simple model, and full National Model, each providing a mutually consistent account of the origin of the long wave but at vastly different levels of explanation and detail, together make a more compelling case for the theory of long waves than any one of them alone.
2. A THEORY OF THE KONDRATIEV CYCLE

The long wave is characterized by successive waves of overexpansion and decline of the economy, particularly the capital producing sectors. Overexpansion means an increase in the capacity to produce and in the production of plant, equipment, and goods relative to the amount needed to replace worn-out units and provide for growth over the long run. Overexpansion is undesirable because eventually, production and employment must be cut back below normal to reduce the excess. Figure 1, from a simulation of the National Model, shows both the short-term business cycle and the periodic buildup and decline of real GNP and its components over about 50 years. Note that real investment fluctuates significantly more than consumption despite being only about one-fifth as large, suggesting the importance of capital investment in the long wave.

How does the long wave arise? In particular, how does overexpansion of production capacity in the economy arise? The National Model identifies several distinct processes which contribute to overexpansion. One of the most fundamental is capital self-ordering, the basis for STRATEGEM-2.

Consider the economy divided into two parts: the capital goods sector and the consumer goods sector. The capital-producing industries of the economy (construction, heavy equipment, steel, mining, and other basic industries) supply each other with the capital, plant, equipment, and materials each needs to operate. Viewed as a whole, the capital sector of the economy orders and acquires capital from itself, hence "self-ordering" (Figure 2).

If the demand for consumer goods and services increases, the consumer goods industry must expand its capacity, and so it places orders for new factories, equipment, vehicles, etc. To supply the higher volume of orders...
the capital-producing sector must also expand its capital stock and places orders for more buildings, machines, rolling stock, trucks, etc., causing the total demand for capital to rise still further, a self-reinforcing spiral of increasing orders, a greater need for expansion, and still more orders. The surge in orders not only boosts desired production directly, it swells the backlogs and depletes the inventories of capital producers, further adding to the pressure for more capital.

Once a capital expansion gets under way, the self-ordering loop amplifies and sustains it until production catches up to orders, excess capacity is built up, and orders begin to fall. At that point, the self-ordering loop reverses: a reduction in orders further reduces the demand for capital, leading to a contraction in the capital sector's output, followed by declining employment, wages, aggregate demand, and production of goods and services. Capital production must remain below the level required for replacement and growth until the excess capacity is depreciated—a process that may take a decade or more due to the long lifetimes of plant and equipment. Once the capital stock is worn out, investment rises, triggering the next upswing.

To illustrate, consider the development of the US economy after World War II. The capital stock of the economy was old and severely depleted after fifteen years of depression and wartime production. The capacity to produce needed goods and capital was itself inadequate. Demand for all types of capital—factories, machines, roads, houses, schools—surged. A massive rebuilding began. In order to replace worn-out capital, fill pent-up demand, and rebuild the capital and infrastructure, the capital-producing sector had to expand beyond the long-run needs of the economy. The necessary, inevitable overexpansion of the capital sector was
exacerbated by self-ordering. As the demand for consumer goods, services, and housing rose, manufacturers of capital plant and equipment had to expand their own capacity, further swelling demand. The resulting high backlogs, spot shortages, high capacity utilization, and rapid growth all reinforced the total demand for capital, helping to ensure that demand did indeed grow. Thus self-ordering powered the boom of the 1950s and 1960s.

By the late 1960s, however, the capital stock had been largely rebuilt, and investment began to slow to a level consistent with replacement and long-run growth. Excess capacity and unemployment began to show up in basic industries. Faced with excess capacity, investment in these industries was cut back, further reducing the need for capital and reinforcing the decline in investment as the economy moved through the 1970s and into the 1980s.

3. OPERATION OF THE GAME

The game can be played manually on a personal computer. This report contains almost everything required to play the manual version of the game. The Playing Board, the Steps of the Game, and a Record Sheet are all included here, and extra copies of each may be ordered in bulk from the authors at MIT. Lacking are only the markers that are used to represent the stocks and flow of capital and orders on the board. These are represented by markers of four different colors, coded for denominations of 10, 50, 100, and 500; all amounts are rounded to the nearest 10 units. These markers may be provided by coins, chips, or other available pieces. When the computer program is not used, it is also helpful for each team to be supplied with a hand calculator to assist in accounting.

The game can also be played entirely on a personal computer. The computer program listed in this report is designed for Microsoft BASIC as
implemented on the IBM PC. Only a few minor changes are necessary to adapt the program to any microcomputer other than the IBM PC. Disks for the IBM PC version can be ordered from the authors at MIT.

The player, or team of players, takes the role of manager for the entire capital-producing sector of the economy. A team with two players per board is most effective for learning, since it forces each player to express verbally the reasons for his/her actions.

Time is divided into two-year periods. At the beginning of each period, orders for capital are received from two sources: the goods sector and the capital sector itself (see the gameboard). Orders for capital arriving from the goods sector are exogenous and determined by drawing a card at the start of each period (or they are specified by the computer). Orders for capital placed by the player in the previous period are moved into the unfilled order backlog for the capital sector. Orders placed by the goods and capital sectors accumulate in the corresponding halves of the rectangle containing the backlog of unfilled orders. The sum of the backlog of orders placed by the goods and capital sectors equals desired production for the current two year period. Production itself is the lesser of desired production or production capacity. Production capacity is determined by the capital stock of the sector. Capital stock is decreased by depreciation and increased by shipments derived from production.

If capacity is inadequate to meet demand fully, available production of capital is allocated between the capital and goods sectors in proportion to their respective backlogs. For example, if the backlog from the capital sector were 500 and the backlog from the goods sector were 1000, desired production would be 1500. If capacity were only 1200, production would be 1200 and the fraction of demand satisfied would be 1200/1500 = 80%. Thus
400 units would be shipped to the capital sector and 800 would be shipped to the goods sector. Any unfilled orders remain in their respective backlogs to be filled in future periods. In the example, 100 units would remain in the backlog of the capital sector and 200 would remain in the backlog of the goods sector. Proportional allocation of output implies that the individual orders for capital placed by firms within the goods and capital sectors each have an equal probability of being filled. Players may wish to experiment with other allocation rules, such as priority for the capital sector.

Note that there is only one decision in the game that is left to the discretion of the player—how much new capital to order for the capital sector in each two-year period. This decision may be made by one player alone or in consultation with one or two others.

The player's goal is to keep production capacity as closely matched to the demand for capital as possible. The game is won by the person or team with the lowest score. The score is the average absolute deviation between production capacity and desired production. Players are thus penalized for excess capacity (which implies underutilized capital) and also for insufficient capacity (which causes shortages of goods elsewhere in the economy).

The game works very well with a variety of individuals ranging from undergraduates to executives to professional systems analysts and economists. One useful protocol for running the game with any of these players is as follows. Introduce the game as an exercise designed to explore investment behavior. Describe the division of the economy into capital- and goods-producing sectors (figure 2), and point out that the production capacity of the capital sector can only be increased by self-ordering. It is not necessary to introduce the phenomenon of the Kondratiev
Wave before the game. Describe the game board and rules, and "talk through" a sample round to demonstrate the mechanics of ordering, producing, and record keeping. Even if the computer program is being used, the players may wish to record all data on the Record Sheet. Describe the scoring rule. Encourage players to ask questions about any aspect of the game. During the game, impose no overt time pressure. Questions that arise during the game should also be answered.

To run the game, the orders for capital placed by the goods sector must be specified. Though a variety of order patterns for the goods sector are possible, the most effective for first-time players is a simple step function in which orders from the goods sector rise from 450 to 500 after the second period and remain at 500 thereafter. The game should be run for about 70 years to show the full pattern of dynamics. Three sheets that may be cut up to provide a deck with this order stream for the manual version of the game are included in this report. The step increase is also incorporated in the computer program for the game. Other patterns of demand can be easily programmed. The pattern of orders should not be revealed to the players in advance.

4. TYPICAL RESULTS OF THE GAME

In almost every game, players increase capital sector orders sufficiently to produce an overexpansion of capacity and subsequent "depression" as investment falls below depreciation and capital is underutilized. Often overcapacity becomes severe enough to cause players to cut orders back to zero. Overexpansion of capacity is not surprising. Since production cannot immediately rise, the increase in demand cannot immediately be met. Thus backlogs are certain to result. To meet the
long-run demand and fill the orders in the backlog, capacity must expand above the equilibrium level. But the magnitude of the capacity overshoot is surprising.

The step increase in orders from the goods sector need only stimulate a rise of just ten percent in the total demand for capital. Due to self-ordering, the equilibrium capital stock rises from 500 to 560, that is, 500 to supply the goods sector and 60 to replace depreciation (10% of 550 is 60 when rounded to the nearest 10). But while orders from the goods sector increase only by 10%, production capacity often expands by many times that amount. Such overexpansion is followed, of course, by long periods of depression required to permit depreciation of the excess capital. When the average lifetime of capital is 20 years, it takes almost 15 years for depreciation to reduce the capital stock by 50%. The average period of the cycle, measured from the first increase in orders to the second, is generally 30 to 50 years.

Two typical games, the result of actual play, are shown in Figures 3 and 4. In both, orders for capital from the goods sector rise from 450 to 500 in year 4, and remain at 500 thereafter. In the first, the player reacted fairly aggressively to the increase in demand by ordering 150 units in year 4. The increase in orders further boosted desired production, leading the player to order still more. Because capacity is inadequate to meet the higher level of demand, unfilled orders accumulate in the backlog, boosting desired production to a peak of 1590 units in year 12, and slowing the growth of capacity. (The fraction of demand satisfied drops to as low as 52 percent, so the capital sector receives less than expected.) Faced with high and rising demand, the player's orders reach 500 in the tenth year. Between years 14 and 16, capacity overtakes demand. Desired
production then falls precipitously as the backlog is depleted, opening a huge margin of excess capacity. Because of unfilled orders in the backlog of the capital sector, capacity continues to rise until year 18, reaching over 1600 units. Note that the total demand for capital rose by just ten percent, but capacity reaches a peak nearly 300 percent greater than its long run equilibrium level. Faced with excess capacity, the player cuts orders back to zero. Capacity then declines through depreciation for the next 24 years. Interestingly, the player allows capacity to undershoot its equilibrium level, initiating a second cycle of similar amplitude and duration. The undershoot of capacity and start of a second cycle is typical and results from the failure of the player to anticipate the two year lag in receiving capital and the failure to realize that the equilibrium level of capacity is greater than 500 (because of the need to replace depreciation).

The second game (figure 4) is much the same. The player here was less aggressive in ordering, resulting in a cycle of lower amplitude (capacity only expands by 200 percent!). Yet the pattern of behavior is the same, including the period (about 40 years) and the phase relationships among the variables.

5. DEBRIEFING THE GAME

About 30-60 minutes should be allowed at the end of the game for debriefing. This is essential if the fun experience of playing the game is to be converted into an effective source of insights about reality. First get the players to recognize and agree on the major perceptions, behavior modes, and motivations they experienced during the game. Then discuss the structural basis in the game for these outcomes. Finally, discuss as a group the counterparts to these structures in real life and the extent to
which outcomes like those in the game have been observed in real economies. The references in this paper will be particularly helpful in this last phase of the debriefing.

The leader should first have the players compute their scores and announce the winner. The pattern of orders, production, and capacity for each player should then be plotted. The juxtaposition of the tiny increase in new orders from the goods sector against the large expansion of capacity makes a dramatic impression and clearly shows that it is the internal management policies followed by each player that create the instability, and not external events that cause the problem. The leader should ask players to describe their feelings during the game, particularly during the phase when capacity was inadequate (years 4 through 14 in figure 3); and at the point where capacity suddenly became excessive (year 16). Discussion of their decisions and rationale should be encouraged. Through questions the leader should get the players to piece together the various stages of their individual order cycle and to relate the results and causes to factors in the real world.

Good leading questions to aid the discussion include: Did you feel in control of the situation or at the mercy of outside forces? What happened that was most surprising? Why did you order $x$ units in year $t$ (indicate a particularly large order near the peak of orders)? Why did it take so long for you to raise production to desired levels? How did you feel when capacity rose above desired production? Why did it take so long for production capacity to fall back to acceptable levels? Why did capacity fall below the equilibrium level?

Emphasize the common pattern of behavior in the different games despite the differences in individual decisions, strategies, and personalities.
Though players typically report that they felt they had little control over the system, they were in fact the only source of change and were fully responsible for the behavior. Discussion of the reasons for this apparent contradiction should be lively. Ask in what ways this aspect of the game might be true for managers in the real world.

It is very important that players learn not to blame the outcome of the game on matters outside their knowledge or control. Point out that the structure and rules of the game are fully known to the players. The state of the system is also fully known. There are no random events or exogenous disturbances after the initial increase in orders. Players were permitted to place any orders they wished, and they suffered little from time pressure. Yet long wave behavior nearly always results. Despite the perfect information and extreme simplicity of the game compared to the actual economy, the cause-effect relationships in the game are complex enough to make it difficult for players to follow what might be termed the optimal strategy.

After the debriefing has covered the players' experience, it is also crucial to help them understand that the long wave behavior they generated did not result from judgmental errors unrelated to the real world. In the real economy information is much less complete and much less certain than it is in STRATEGEM-2, and the structure of the economy, particularly the interconnections among firms, is not fully appreciated. In addition, the long time required in real life for the consequences of self-ordering to manifest itself reduces the likelihood that corporate and government managers will learn from experience. Learning is also hindered by the heavy weight placed on relatively recent information compared to what happened in previous decades. And over a fifty year cycle, many of the leaders who
experienced the transition from expansion to contraction have retired or died by the next expansion period. A particularly ironic example is the behavior of the banking system in the current international debt crisis—a nearly exact replica of the 1920s and 1930s.

6. CONCLUSION

STRATEGEM-2 provides a simple and dramatic demonstration of the way in which investment decisions can lead to instability in the economy, and to long waves in particular. It shows how micro-level decisions lead to the macro-behavior of systems. In particular, it shows how individual decisions, though seemingly rational at the time, can lead to undesirable behavior for the system as a whole, even when perfect information is available and the full structure of the system is known. It points out the importance of considering both flow and stock variables, such as the buildup of backlogs, in the genesis of dynamic behavior. The game illustrates the extent to which dynamic behavior is created by the internal structure of systems and not by external events. It provides a good introduction to the use of behavioral models in the study of economic dynamics. Finally, it illustrates the educational power of simple games when they are based on small but sophisticated computer models.
APPENDIX: EQUATIONS AND PARAMETERS FOR THE GAME

The following equations correspond exactly to the structure of the game (see also the simple model in Sterman 1984b).

\[
\text{PRODUCTION}(t) = \min[\text{DESIRED PRODUCTION}(t), \text{CAPACITY}(t)] \tag{1}
\]

Production over the current two-year cycle is the lesser of desired production or production capacity.

\[
\text{CAPACITY}(t) = (dt)(\text{CAPITAL}(t)/\text{CAPITAL-OUTPUT RATIO}) \tag{2}
\]

\[
\text{CAPITAL-OUTPUT RATIO} = 2 \text{ years}
\]

Annual production capacity is given by capital stock divided by the capital-output ratio. Capacity for the next time period of length \((dt)\) is the annual rate times \((dt)\), which is two years. For simplicity, the capital output ratio is assumed to be two, and thus production capacity for each two year period equals the capital stock.

\[
\text{CAPITAL}(t+dt) = \text{CAPITAL}(t) + \text{SHIPMENTS TO CAPITAL SECTOR}(t) - \text{DEPRECIATION}(t) \tag{3}
\]

The capital stock is increased by shipments of capital to the capital sector and decreased by depreciation.

\[
\text{DEPRECIATION}(t) = (dt)(\text{CAPITAL}(t)/\text{AVERAGE LIFETIME OF CAPITAL}) \tag{4}
\]

\[
\text{AVERAGE LIFETIME OF CAPITAL} = 20 \text{ years}
\]
Depreciation is proportional to the capital stock. The average life of capital is assumed to be 20 years, so in each period of two years, 10 percent of the capital stock is lost.

\[
\text{SHIPMENTS TO CAPITAL SECTOR}(t) = \text{BACKLOG OF CAPITAL SECTOR}(t) \times \text{FRACTION OF DEMAND SATISFIED}(t)
\]  \hspace{1cm} (5)

\[
\text{SHIPMENTS TO GOODS SECTOR}(t) = \text{BACKLOG OF GOODS SECTOR}(t) \times \text{FRACTION OF DEMAND SATISFIED}(t)
\]  \hspace{1cm} (6)

\[
\text{FRACTION OF DEMAND SATISFIED}(t) = \frac{\text{PRODUCTION}(t)}{\text{DESIRED PRODUCTION}(t)}
\]  \hspace{1cm} (7)

Available capital is allocated between the goods and capital sectors in proportion to the fraction of demand satisfied, thus insuring that each sector has equal access to the total supply of capital.

\[
\text{DESIRED PRODUCTION}(t) = \text{BACKLOG OF CAPITAL SECTOR}(t) + \text{BACKLOG OF GOODS SECTOR}(t)
\]  \hspace{1cm} (8)

Desired production is the sum of the backlogs of unfilled orders for capital placed by the goods and the capital sectors. The normal delay in receiving capital is therefore \((dt)\) or two years.

\[
\text{BACKLOG OF CAPITAL SECTOR}(t+dt) = \text{BACKLOG OF CAPITAL SECTOR}(t) + \text{NEW ORDERS FROM CAPITAL SECTOR}(t) - \text{SHIPMENTS TO CAPITAL SECTOR}(t)
\]  \hspace{1cm} (9)
\[
\text{BACKLOG OF GOODS SECTOR}(t+\Delta t) = \text{BACKLOG OF GOODS SECTOR}(t) + \\
\quad \text{NEW ORDERS FROM GOODS SECTOR}(t) - \\
\quad \text{SHIPMENTS TO GOODS SECTOR}(t) 
\]

The backlogs of the goods and capital sectors are increased by the new orders placed by each sector and decreased by shipments to each sector. New orders for capital placed by the capital sector are determined by the player. New orders for capital placed by the goods sector are exogenous.

\[
\text{SCORE} = \sum \left| \frac{\text{DESISHED PRODUCTION}(t) - \text{CAPACITY}(t)}{\text{NUMBER OF PERIODS}} \right| 
\]

The player's score is the absolute deviation between desired production and production capacity averaged over the number of periods played. Thus the score indicates how well the player has matched demand and supply. The player is penalized for both excess demand and excess supply. If demand exceeds supply, the growth of the economy is hampered. If supply exceeds demand, the resources of the economy are misallocated and standing idle.

The game can be initialized in equilibrium with the goods sector ordering 450 units each period, a capital stock of 500 units and total backlog of 500 units. Desired production and production capacity are therefore in balance. The backlog of the goods sector is 450 units and that of the capital sector is 50 units, just enough to offset the impending depreciation of 50 units of capital.
REFERENCES


Figure 1: Simulation of the National Model, showing the business cycle and long wave (Sterman 1984a)
Figure 2: Self-ordering of capital

Diagram shows the flow between labor, capital sector, consumer goods sector, and orders for capital.
Figure 3: Actual results of the game. Orders from the goods sector rise from 450 to 500 in year 4. Note the amplitude of capacity compared to that of the orders for capital placed by the goods sector. The period of the cycle is about 38 years.
Figure 3 (cont.): Actual results of the game (printed by the computer program).

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Score: 509

0. New orders from goods sector
1. Backlog of unfilled orders from goods sector
2. Backlog of unfilled orders from capital sector
3. Desired production \([=1+2]\)
4. Production capacity
5. Depreciation of capital stock
6. Production \([=\text{MIN}(3,4)]\)
7. Fraction of demand satisfied \([=6/3]\)
8. Shipments to the goods sector \([=7*1]\)
9. Shipments to the capital sector \([=6-8]\)
10. New orders from capital sector
Figure 4: Actual results of the game. In this game, the player was less aggressive in ordering capital, thus reducing the amplitude of the cycle (note the vertical scale). The second cycle also has a smaller amplitude than the first, as the player learned to control the system.
Figure 4 (cont.): Actual results of the game.

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Score: 164

0. New orders from goods sector
1. Backlog of unfilled orders from goods sector
2. Backlog of unfilled orders from capital sector
3. Desired production [=1+2]
4. Production capacity
5. Depreciation of capital stock
6. Production [=MIN(3,4)]
7. Fraction of demand satisfied [=6/3]
8. Shipments to the goods sector [=7+1]
9. Shipments to the capital sector [=8-8]
10. New orders from capital sector
D-3634-1

Listing of computer program

10 ' KONDRATIEV WAVE GAME
20 ' JOHN D. STERMAN, JULY 1984
40 ' COPYRIGHT (C) 1984 BY SYSTEM DYNAMICS GROUP
60 ' SLOAN SCHOOL OF MANAGEMENT
70 ' E40-294
80 ' MASSACHUSETTS INSTITUTE OF TECHNOLOGY
90 ' CAMBRIDGE MA 02139
100 ' DEFINITIONS
120 ' BG = BACKLOG OF GOODS SECTOR
130 ' BC = BACKLOG OF CAPITAL SECTOR
150 ' D = DEPRECIATION OF CAPITAL STOCK
160 ' DS = FRACTION OF DEMAND SATISFIED
170 ' NC = NEW ORDERS FROM CAPITAL SECTOR
180 ' NG = NEW ORDERS FROM GOODS SECTOR
190 ' NG1 = AVERAGE ORDERS AFTER STEP IN YEAR 4
200 ' PC = CAPITAL STOCK
210 ' D = DEPRECIATION OF CAPITAL STOCK
220 ' PR = PRODUCTION
230 ' RR = RANGE OF RANDOMNESS
240 ' S = SCORE
250 ' SC = SHIPMENTS TO CAPITAL SECTOR
260 ' SG = SHIPMENTS TO GOODS SECTOR
270 ' DELAY LOOP FOR FIRST SCREEN
280 ' KEY OFF
300 CLS
320 PRINT:PRINT:PRINT:PRINT:PRINT
330 PRINT " KONDRATIEV GAME"
340 PRINT
350 PRINT
360 XYZ%=XYZ%+1
370 PRINT " J. STERMAN, 1984"
380 FOR TMLP%=0 TO 800 STEP 1
390 NEXT TMLP%
400 CLS
420 ' INITIAL VALUES
440 ' COMPUTATIONAL LOOP, 70 YEARS
460 DIM R(11,36)
470 PC%=500
480 NC%=50
490 ' COMPUTATIONAL LOOP, 70 YEARS
500 ' RR%=0
530 NG1%=500 'Average orders after step in year 4
540 FOR T%=0 TO 70 STEP 2
550 IF T%=2 THEN NG%=450 ELSE NG%=NG%+INT(((RND-.5)*RR%)/10)*10
560 BC%=BC%+NC%
570 BG%=BG%+NG%
580 DP%=BC%+BG%
590 PC%=PC%+SC%-D%
D-3634-1

600 ' COMPUTATION OF SCORE
610 ' Production and fraction of demand satisfied
620 ' IF PC%>DP% THEN PR%=DP% ELSE PR%=PC%
630 S1%=ABS(DP%-PC%)/100
640 S2%=S1%+S1%
650 S%=100*S2%/((T%/2)+1)
660 ' Write values into results matrix
670 ' R(1,T%/2+1)=NG%
680 R(2,T%/2+1)=BG%
690 R(3,T%/2+1)=BC%
700 R(4,T%/2+1)=DP%
710 R(5,T%/2+1)=PC%
720 ' CALCULATE NEW RATES
730 D%=INT(((PC%*.1)/10)+.5)*10
740 SG%=INT(((DS%/100)*BG%)/10+.5)*10
750 ' More results...
760 ' R(6,T%/2+1)=D%
770 R(7,T%/2+1)=PR%
780 R(8,T%/2+1)=DS%
790 R(9,T%/2+1)=SG%
800 R(10,T%/2+1)=SC%
810 ' PRINT CURRENT PERIOD VALUES
820 CLS
830 PRINT " Year ";T%
840 PRINT " 0. New orders from goods sector ";NG%
850 PRINT " 1. Backlog of goods sector ";BG%
860 PRINT " 2. Backlog of capital sector ";BC%
870 PRINT " 3. Desired production ";DP%
880 PRINT " 4. Capital stock ";PC%
890 PRINT " 5. Depreciation ";D%
900 PRINT " 6. Production ";PR%
910 PRINT " 7. Fraction of demand satisfied ";DS%
920 PRINT " 8. Ship. to goods sector ";SG%
930 PRINT " 9. Ship. to capital sector ";SC%
940 PRINT " 10. New orders for cap. sector";NC
1140 ' CHECK FOR INVALID ENTRIES
1150 '  
1160 '  
1170 IF NC>=0 THEN 1200
1180 BEEP:PRINT "You must enter a positive number, try again" 
1190 GOTO 1130
1200 IF NC<32760 THEN 1260
1210 BEEP:PRINT "you must enter a smaller number, try again" 
1220 GOTO 1130
1230 '  
1240 ' ROUND NEW ORDERS TO NEAREST 10 UNITS
1250 '  
1260 NC%=INT((NC/10)+.5)*10
1270 '  
1280 R(11,T%/2+1)=NC% 'Write new orders into results matrix
1290 '  
1300 INPUT "<return> to continue, <q> to quit, <p> to plot";C$
1310 BC%=BC%-SC%
1320 BG%=BG%-SG%
1330 IF C$="q" OR C$="Q" THEN 1400
1340 IF C$="p" OR C$="P" THEN 1520
1350 '  
1360 NEXT T%
1370 '  
1380 ' PRINT SCORE
1390 '  
1400 CLS
1410 PRINT:PRINT:PRINT:PRINT
1420 PRINT USING "Your score was %s;S%" 
1430 PRINT USING "Congratulations, you should be managing the economy!" 
1440 PRINT USING "Nice Job!" 
1450 IF 100<S% AND S%<=200 THEN PRINT "Surf's up!"
1460 IF S%>200 THEN PRINT " 
1470 PRINT:PRINT:PRINT:PRINT:PRINT:PRINT
1480 PRINT:PRINT:PRINT:PRINT:PRINT:PRINT
1490 INPUT "<return> to plot results, q to quit";P$
1500 IF P$="q" OR P$="Q" THEN 2190
1520 '  
1530 ' PLOTTING SUBROUTINE
1540 '  
1550 YM%=250 'Maximum value on vertical scale
1560 SCREEN 0,0;CLS
1570 TIMEND=T%-2
1580 '  
1590 ' PRINT TIME AXIS
1600 '  
1610 FOR LABEL=0 TO 65 STEP 5
1620 PLABEL=LABEL+8
1630 LOCATE 22,PLABEL;PRINT LABEL;
1640 NEXT LABEL
1650 '  
1660 ' PRINT LEGEND
1670 '  
1680 LOCATE 24,1
1690 PRINT "G = NEW ORDERS FROM GOODS SECTOR  C = NEW ORDERS FROM CAPITAL SECTOR P R;"
1700 LOCATE 25,1
1710 PRINT "P = PRODUCTION  S = CAPITAL STOCK  D = DESIRED PRODUCTION";
1720 ' PRINT GRID
1730 ' PRINT GRID
1740 ' PRINT GRID
1750 FOR HGRID%=8 TO 80 STEP 1
1760 LOCATE 21,HGRID%
1770 PRINT "-";
1780 NEXT HGRID%
1790 FOR VGRID%=-1 TO 21 STEP 1
1800 LOCATE VGRID%,8
1810 PRINT "|"
1820 NEXT VGRID%
1830 ' PRINT VERTICAL SCALE
1840 ' PRINT VERTICAL SCALE
1850 ' PRINT VERTICAL SCALE
1860 FOR VLABEL%=-1 TO 21 STEP 4
1870 LOCATE VLABEL%,1:PRINT (YM%/20)*(21-VLABEL%)
1880 NEXT VLABEL%
1890 ' PRINT SCORE
1900 ' PRINT SCORE
1910 ' PRINT SCORE
1920 LOCATE 1,68:PRINT "SCORE= ";S%
1930 ' PRINT SCORE
1940 ' PRINT SCORE
1950 ' PRINT SCORE
1960 FOR I=1 TO 11
1961 ' Don't print variables 2,3,6,8,9, or 10
1962 ' Don't print variables 2,3,6,8,9, or 10
1963 IF I=2 OR I=3 OR I=6 OR I=8 OR I=9 OR I=10 THEN GOTO 2060
1964 IF I=2 OR I=3 OR I=6 OR I=8 OR I=9 OR I=10 THEN GOTO 2060
1965 FOR TPLLOT=0 TO TIMEND STEP 2
1966 IF R(I,TPLLOT/2+1)*20/YM%>20 THEN Y=1 ELSE IF R(I,TPLLOT/2+1)*20/YM%<1
1967 THEN Y=21 ELSE Y=21-R(I,TPLLOT/2+1)*20/YM%
1968 X=TPLLOT+9
1969 LOCATE Y,X
1970 IF I=1 THEN PRINT "G"; ELSE IF I=11 THEN PRINT "C";
1971 IF I=1 THEN PRINT "G"; ELSE IF I=11 THEN PRINT "C";
1972 IF I=4 THEN PRINT "D"; ELSE IF I=5 THEN PRINT "S"; ELSE IF I=7
1973 THEN PRINT "P";
1974 NEXT TPLLOT
1975 INPUT Z$
1976 NEXT I
1977 ' ask for replot
1978 ' ask for replot
1979 ' ask for replot
2000 X=TPLLOT+9
2010 LOCATE Y,X
2020 IF I=1 THEN PRINT "G"; ELSE IF I=11 THEN PRINT "C";
2030 IF I=1 THEN PRINT "G"; ELSE IF I=11 THEN PRINT "C";
2040 NEXT TPLLOT
2050 INPUT Z$
2060 NEXT I
2070 ' ask for replot
2080 ' ask for replot
2090 ' ask for replot
2100 LOCATE 25,1:PRINT
2110 INPUT "Do you want to re-plot results on another scale <y/n>";PLOTS$
2120 IF PLOTS$="y" AND PLOTS$="Y" THEN 2150
2130 INPUT "Enter the maximum value for the vertical axis";YM%
2140 GOTO 1560
2150 IF C$="p" OR C$="P" THEN 1360
2160 ' PRINTOUT OF RESULTS
2170 PRINT: INPUT "Do you want a printout of the results <y/n>" ; PR$  
2180 IF PR$<>"y" AND PR$<>"Y" THEN GOTO 2440  
2190 LPRINT "YEAR"  
2200 LPRINT  
2210 LPRINT " 0. 1. 2. 3. 4. 5. 6. 7. 8. 9. 10."  
2220 LPRINT  
2230 FOR T%-0 TO 70 STEP 2  
2240 LPRINT USING "@@ @@ @@ @@ @@ @@ @@ @@ @@ @@ @@@@ @@@@ @@@@ @@@@ @@@@ @@@@ @@@@ @@@@ @@@@ @@@@ @@@@ @@@@ @@@@ @@@@ @@@@ @@@@ @@@@ @@@@ @@@@ @@@@ @@@@ @@@@ @@@@ @@@@ @@@@ @@@@ @@@@ @@@@ @@@@ @@@@ @@@@ @@@@ @@@@ @@@@ @@@@ @@@@ @@@@ @@@@ @@@@@@ @@@@@@@@ @@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
STEPS OF THE GAME

1. RECEIVE NEW ORDERS FROM THE GOODS SECTOR INTO THE BACKLOG
   Turn over the top card on the order deck. Transfer the indicated quantity of markers into the BACKLOG OF UNFULFILLED ORDERS for the goods sector. Record the goods sector backlog in row 1 of the record sheet.

2. RECEIVE NEW ORDERS FROM THE CAPITAL SECTOR INTO THE BACKLOG
   Transfer the markers in the box marked NEW ORDERS -- CAPITAL SECTOR into the BACKLOG OF UNFULFILLED ORDERS for the capital sector. Record the capital sector backlog in row 2 of the record sheet.

3. CALCULATE DESIRED PRODUCTION
   Desired production equals the total BACKLOG OF UNFULFILLED ORDERS from both the goods and capital sectors. Add row 1 to row 2 or count the total backlog and enter in row 3 of the record sheet.

4. CALCULATE PRODUCTION CAPACITY
   Production capacity for the next period is equal to the capital stock. Count the contents of the CAPITAL STOCK and enter in row 4 of the record sheet.

5. DEPRECIATE THE CAPITAL STOCK
   Each period one-tenth of the CAPITAL STOCK is lost through depreciation. Calculate depreciation as 10% of the CAPITAL STOCK (row 4). Round off to the nearest ten units. Record in row 5. Remove the markers from the CAPITAL STOCK.

6. CALCULATE PRODUCTION
   Production is the lesser of desired production (row 3) and production capacity (row 4). Record in row 6.

7. CALCULATE THE FRACTION OF DEMAND SATISFIED
   Compute the ratio of production (row 6) to desired production (row 3). This ratio is the fraction of demand you are able to satisfy.

8. SHIP OUTPUT TO THE GOODS SECTOR
   Shipments to the goods sector equal the BACKLOG OF UNFULFILLED ORDERS of the goods sector (row 1) times the fraction of demand satisfied (row 7). Record shipments in row 8. Transfer the indicated number of markers out of the BACKLOG OF UNFULFILLED ORDERS of the goods sector and off the board.

9. SHIP OUTPUT TO THE CAPITAL SECTOR
   Shipments to the capital sector equal the BACKLOG OF UNFULFILLED ORDERS of the capital sector (row 2) times the fraction of demand satisfied (row 7). Record shipments in row 9. Transfer the indicated number of markers from the BACKLOG OF UNFULFILLED ORDERS of the capital sector into the CAPITAL STOCK.

10. PLACE ORDERS FOR NEW CAPITAL
    Decide how much capital you wish to order. Record your order in row 10. Place the indicated number of markers in the box marked NEW ORDERS -- CAPITAL SECTOR.
**Goods Sector Order Deck**

Cut these out and place face down on the board. The two orders for 450 units should be on top.

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<td>DEPRECIATION = 10% OF CAPACITY</td>
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<td>PRODUCTION = MINIMUM [(3),(4)]</td>
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<td>FRACTION OF DEMAND SATISFIED (6)/(3)</td>
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<td>SHIPMENTS TO GOODS SECTOR (1)*(7)</td>
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<td>SHIPMENTS TO CAPITAL SECTOR (2)*(7)</td>
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<td>3. DESIRED PRODUCTION = (1) + (2)</td>
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