STRATAGEM-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 so 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.

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, 1870-1890s, 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 1985a). 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 1985a, 1985b). The theory emerging from the National Model explains the long wave as the endogenous result of decision making 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 1985b). 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 underexpansion 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 article describes a simulation game that 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 underexpansion 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.

A THEORY OF THE KONDRATIEV CYCLE

The long wave is characterized by successive waves of over-expansion and decline of the economy, particularly the capital
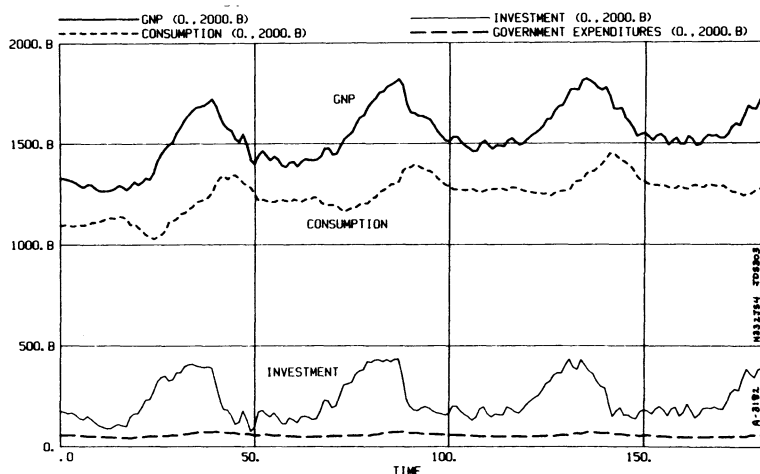
Figure 1: Simulation—Components of Real GNP

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 that 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
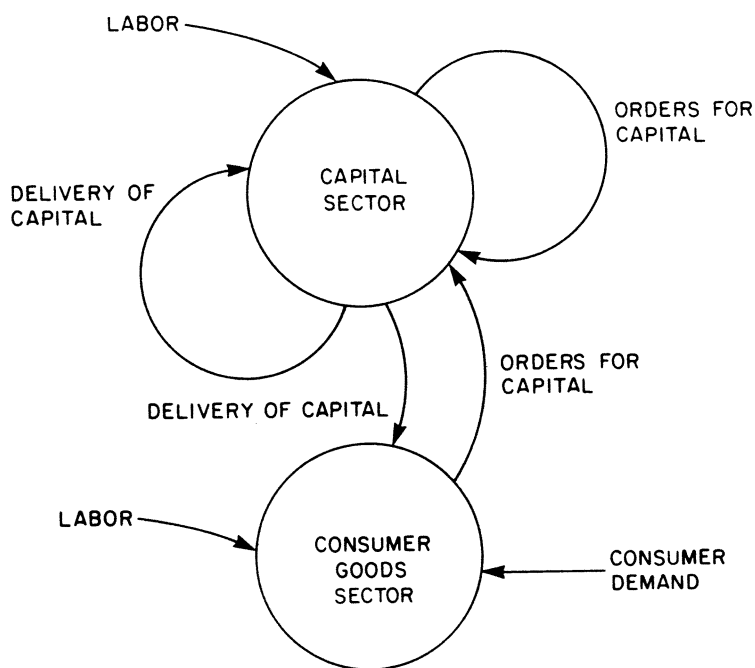
Figure 2

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" (see 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, and so on. 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, and so on,

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 un-

employment 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.

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 (see Appendix B), the Steps of the Game (see Appendix C), and a Record Sheet (see Appendix D) 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 article (see Appendix E) 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. (Please specify color or monochrome. Versions for other popular microcomputers are under development.)

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, because 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. Proportion-al 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 over 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. A sheet that may be cut up to provide a deck with this order stream for the manual version of the game is included in this article, (see Appendix F). 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.

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. Because 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 10% 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 although 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 Figure 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%, so the capital sector receives less than expected.) Faced with high and rising demand, the player's orders reach 500
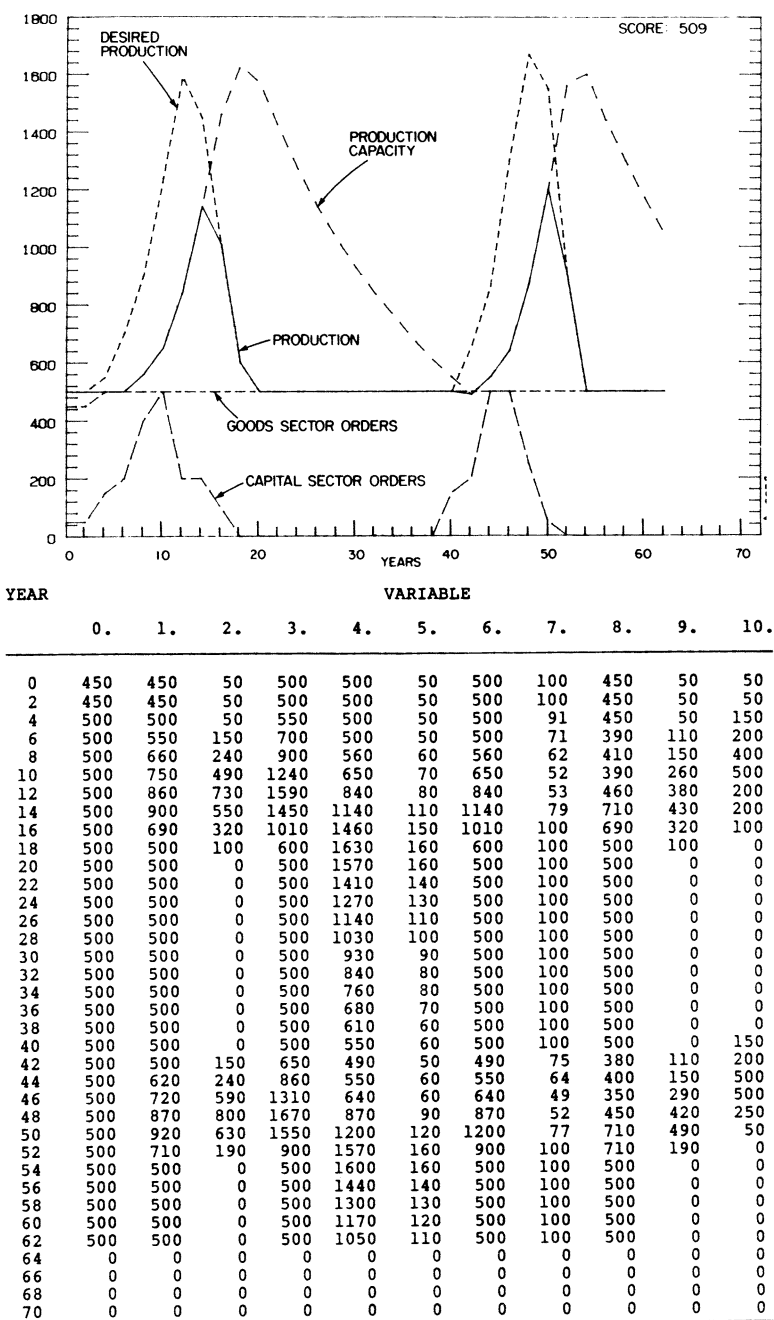
YEAR					VARIABLE					
	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
0	450	450	50	500	500	50	500	100	450	50	50
2	450	450	50	500	500	50	500	100	450	50	50
4	500	500	50	550	500	50	500	91	450	50	150
6	500	550	150	700	500	50	500	71	390	110	200
8	500	660	240	900	560	60	560	62	410	150	400
10	500	750	490	1240	650	70	650	52	390	260	500
12	500	860	730	1590	840	80	840	53	460	380	200
14	500	900	550	1450	1140	110	1140	79	710	430	200
16	500	690	320	1010	1460	150	1010	100	690	320	100
18	500	500	100	600	1630	160	600	100	500	100	0
20	500	500	0	500	1570	160	500	100	500	0	0
22	500	500	0	500	1410	140	500	100	500	0	0
24	500	500	0	500	1270	130	500	100	500	0	0
26	500	500	0	500	1140	110	500	100	500	0	0
28	500	500	0	500	1030	100	500	100	500	0	0
30	500	500	0	500	930	90	500	100	500	0	0
32	500	500	0	500	840	80	500	100	500	0	0
34	500	500	0	500	760	80	500	100	500	0	0
36	500	500	0	500	680	70	500	100	500	0	0
38	500	500	0	500	610	60	500	100	500	0	0
40	500	500	0	500	550	60	500	100	500	0	150
42	500	500	150	650	490	50	490	75	380	110	200
44	500	620	240	860	550	60	550	64	400	150	500
46	500	720	590	1310	640	60	640	49	350	290	500
48	500	870	800	1670	870	90	870	52	450	420	250
50	500	920	630	1550	1200	120	1200	77	710	490	50
52	500	710	190	900	1570	160	900	100	710	190	0
54	500	500	0	500	1600	160	500	100	500	0	0
56	500	500	0	500	1440	140	500	100	500	0	0
58	500	500	0	500	1300	130	500	100	500	0	0
60	500	500	0	500	1170	120	500	100	500	0	0
62	500	500	0	500	1050	110	500	100	500	0	0
64	0	0	0	0	0	0	0	0	0	0	0
66	0	0	0	0	0	0	0	0	0	0	0
68	0	0	0	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0	0	0	0

Figure 3

Score: 509

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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 [=6-8]
10.   New orders from capital sector
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Figure 3 (Continued)

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 10%, but capacity reaches a peak nearly 300% 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 (see 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%!). Yet the pattern of behavior is the same, including the period (about 40 years) and the phase relationships among the variables.

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
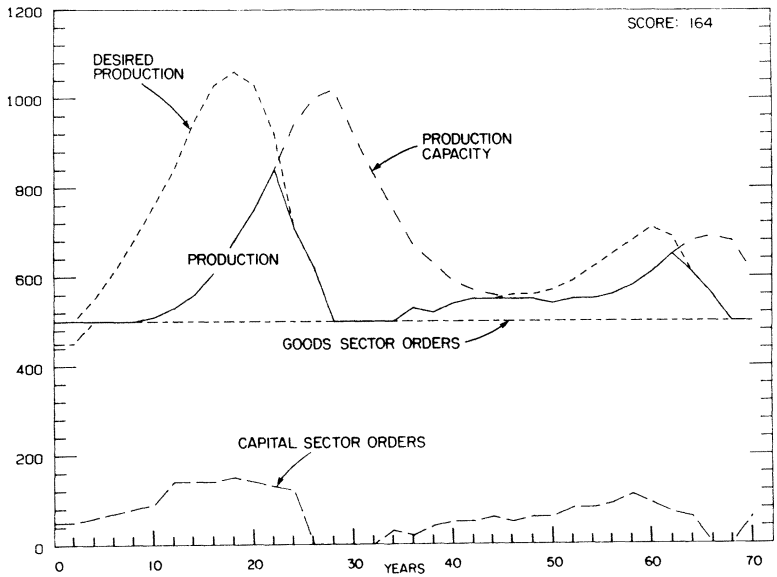
YEAR   VARIABLE

YEAR	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
0	450	450	50	500	500	50	500	100	450	50	50
2	450	450	50	500	500	50	500	100	450	50	50
4	500	500	50	550	500	50	500	91	450	50	60
6	500	550	60	610	500	50	500	82	450	50	70
8	500	600	80	680	500	50	500	74	440	60	80
10	500	660	100	760	510	50	510	67	440	70	90
12	500	720	120	840	530	50	530	63	450	80	140
14	500	770	180	950	560	60	560	59	450	110	140
16	500	820	210	1030	610	60	610	59	480	130	140
18	500	840	220	1060	680	70	680	64	540	140	150
20	500	800	230	1030	750	80	750	73	580	170	140
22	500	720	200	920	840	80	840	91	660	180	130
24	500	560	150	710	940	90	710	100	560	150	120
26	500	500	120	620	1000	100	620	100	500	120	0
28	500	500	0	500	1020	100	500	100	500	0	0
30	500	500	0	500	920	90	500	100	500	0	0
32	500	500	0	500	830	80	500	100	500	0	0
34	500	500	0	500	750	80	500	100	500	0	30
36	500	500	30	530	670	70	530	100	500	30	20
38	500	500	20	520	630	60	520	100	500	20	40
40	500	500	40	540	590	60	540	100	500	40	50
42	500	500	50	550	570	60	550	100	500	50	50
44	500	500	50	550	560	60	550	100	500	50	60
46	500	500	60	560	550	60	550	98	490	60	50
48	500	510	50	560	550	60	550	98	500	50	60
50	500	510	60	570	540	50	540	95	480	60	60
52	500	530	60	590	550	60	550	93	490	60	80
54	500	540	80	620	550	60	550	89	480	70	80
56	500	560	90	650	560	60	560	86	480	80	90
58	500	580	100	680	580	60	580	85	490	90	110
60	500	590	120	710	610	60	610	86	510	100	90
62	500	580	110	690	650	70	650	94	550	100	70
64	500	530	80	610	680	70	610	100	530	80	60
66	500	500	60	560	690	70	560	100	500	60	0
68	500	500	0	500	680	70	500	100	500	0	0
70	500	500	0	500	610	60	500	100	500	0	60

Figure 4

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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 [=6-8]
10.   New orders from capital sector
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Figure 4 (Continued)

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 article 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 informa-

tion 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.

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 A
Equations and Parameters for the Game

The following equations correspond exactly to the structure of the game (see also the simple model in Sterman 1985b).

$$\text{Production}(t) = \text{Min}[\text{Desired Production}(t), \text{Capacity}(t)] \quad [1]$$

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

Capacity(t) = (dt)(Capital(t)/Capital-Output Ratio)
Capital-Output Ratio = 2 years   [2]

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.

Capital(t + dt) = Capital(t) + Shipments to Capital Sector(t) –
                         Depreciation(t)   [3]

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

Depreciation(t) = (dt)(Capital(t)/Average Lifetime of Capital)
Average Lifetime of Capital = 20 years   [4]

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% of the capital stock is lost.

Shipments to Capital Sector(t) = Backlog of Capital Sector(t)*
                         Fraction of Demand Satisfied(t) [5]

Shipments to Goods Sector(t) = Backlog of Goods Sector(t)*
                         Fraction of Demand Satisfied(t) [6]

$$\text{Fraction of Demand Satisfied(t)} = \frac{\text{Production(t)}}{\text{Desired Production(t)}} \quad [7]$$

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

Desired Production(t) = Backlog of Capital Sector(t) +
                         Backlog of Goods Sector(t)   [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.

Backlog of Capital Sector(t + dt) = Backlog of Capital
Sector(t) +
New Orders from Capital
Sector(t) –
Shipments to Capital
Sector(t)   [9]

Backlog of Goods Sector(t + dt) = Backlog of Goods Sector(t) +
New Orders from Goods
Sector(t) –
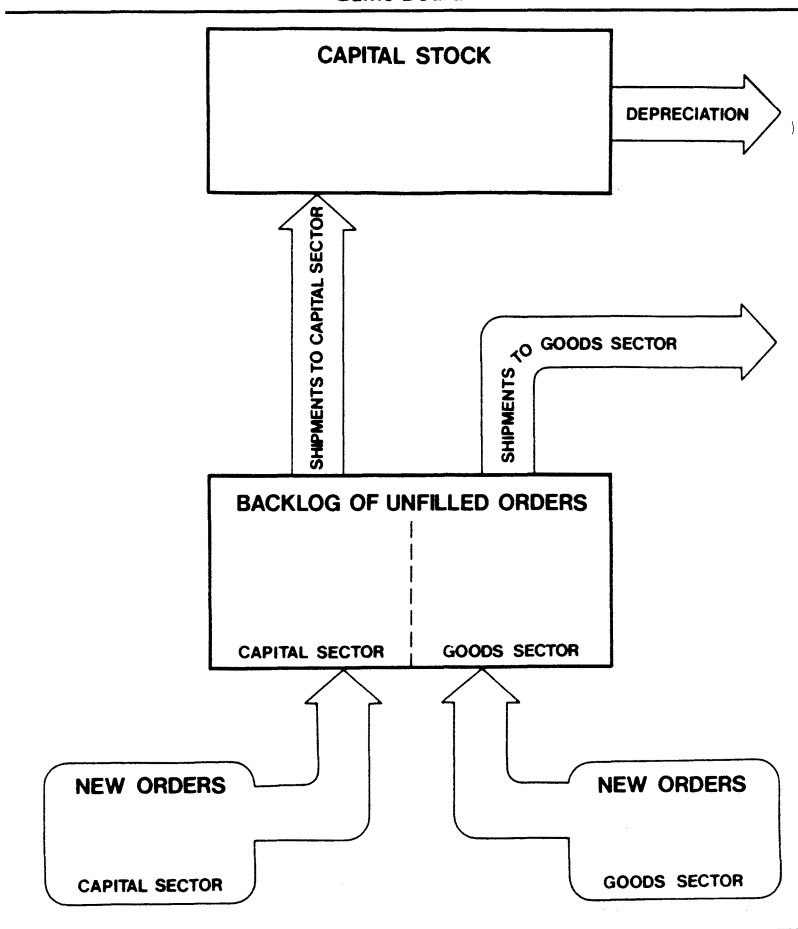Shipments to Goods Sector(t) [10]

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.

$$\text{Score} = \frac{\text{Sum}[\,|\,\text{Desired Production}(t) - \text{Capacity}(t)|\,]}{\text{Number of Periods}} \qquad [11]$$

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 produc-
tion 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.

APPENDIX B
Game Board

CAPITAL STOCK

DEPRECIATION

SHIPMENTS TO CAPITAL SECTOR

SHIPMENTS TO GOODS SECTOR

BACKLOG OF UNFILLED ORDERS

CAPITAL SECTOR | GOODS SECTOR

NEW ORDERS

CAPITAL SECTOR

NEW ORDERS

GOODS SECTOR

APPENDIX C
Steps of the Game

(1) **RECEIVE NEW ORDERS FROM THE GOODS SEC-
TOR INTO THE BACKLOG**
Turn over the top card on the order deck. Transfer the
indicated quantity of markers into the BACKLOG OF
UNFILLED ORDERS for the goods sector. Record the
goods sector backlog in row 1 of the record sheet.

(2) **RECEIVE NEW ORDERS FROM THE CAPITAL SEC-
TOR INTO THE BACKLOG**
Transfer the markers in the box marked NEW ORDERS—
CAPITAL SECTOR into the BACKLOG OF UNFILLED
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 UN-
FILLED 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 SAT-
ISFIED**
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
UNFILLED 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 UNFILLED 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
UNFILLED 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 UNFILLED 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.

APPENDIX D
Record Sheet

YEAR	0	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34
1. BACKLOG OF U. ORDERS FROM GOODS SECTOR																		
2. BACKLOG OF U. ORDERS FROM CAPITAL SECTOR																		
3. DESIRED PRODUCTION = (1) + (2)																		
4. PRODUCTION CAPACITY = CAPITAL STOCK																		
5. DEPRECIATION = 10% OF CAPACITY																		
6. PRODUCTION = MINIMUM [(3),(4)]																		
7. FRACTION OF DEMAND SATISFIED (6)/(3)																		
8. SHIPMENTS TO GOODS SECTOR (1)*(7)																		
9. SHIPMENTS TO CAPITAL SECTOR (2)*(7)																		
10. NEW ORDERS FOR CAPITAL																		

(continued)

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APPENDIX D (Continued)

YEAR	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70
1. BACKLOG OF U. ORDERS FROM GOODS SECTOR																		
2. BACKLOG OF U. ORDERS FROM CAPITAL SECTOR																		
3. DESIRED PRODUCTION = (1) + (2)																		
4. PRODUCTION CAPACITY = CAPITAL STOCK																		
5. DEPRECIATION = 10% OF CAPACITY																		
6. PRODUCTION = MINIMUM [(3),(4)]																		
7. FRACTION OF DEMAND SATISFIED (6)/(3)																		
8. SHIPMENTS TO GOODS SECTOR (1)*(7)																		
9. SHIPMENTS TO CAPITAL SECTOR (2)*(7)																		
10. NEW ORDERS FOR CAPITAL																		

NAME: _____   SCORE: _____   DATE: _____

APPENDIX E
Listing of Computer Program (monochrome version)

```
10 ' KONDRATIEV WAVE GAME
20 '
30 ' JOHN D. STERMAN, JULY 1984
40 '
50 ' COPYRIGHT (C) 1984 BY SYSTEM DYNAMICS GROUP
60 ' SLOAN SCHOOL OF MANAGEMENT
70 ' E40-294
80 ' MASSACHUSSETTS INSTITUTE OF TECHNOLOGY
90 ' CAMBRIDGE MA 02139
100 '
110 '
120 ' DEFINITIONS
130 '
140 '    BG = BACKLOG OF GOODS SECTOR
150 '    BC = BACKLOG OF CAPITAL SECTOR
152 '     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 SCTOR
270 '
280 ' DELAY LOOP FOR FIRST SCREEN
290 '
300 KEY OFF
310 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 XYZ%=XYZ%+1
410 NEXT TMLP%
420 CLS
430 '
440 ' INITIAL VALUES
450 '
460 DIM R(11,36)
470 PC%=500
480 NC%=50
490 '
500 ' COMPUTATIONAL LOOP, 70 YEARS
510 '
520 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%=NG1%+INT(((RND-.5)*RR%)/10)*10
560 BC%=BC%+NC%
570 BG%=BG%+NG%
580 DP%=BC%+BG%
590 PC%=PC%+SC%-D%
```

(continued)

APPENDIX E Continued

```
600 '
610 ' COMPUTATION OF SCORE
620 '
630 S1%=ABS(DP%-PC%)/100
640 S2%=S2%+S1%
650 S%=100*S2%/((T%/2)+1)
660 '
665 ' Production and fraction of demand satisfied
670 '
680 IF PC%>DP% THEN PR%=DP% ELSE PR%=PC%
690 DS%=INT(((PR%/DP%)+.005)*100)
692 '
693 ' Write values into results matrix
694 '
700 R(1,T%/2+1)=NG%
710 R(2,T%/2+1)=BG%
720 R(3,T%/2+1)=BC%
730 R(4,T%/2+1)=DP%
740 R(5,T%/2+1)=PC%
750 '
760 ' CALCULATE NEW RATES
770 '
780 D%=INT((PC%*.1/10)+.5)*10
790 SG%=INT(((DS%/100)*BG%)/10+.5)*10
800 SC%=PR%-SG%
810 '
812 ' More results...
814 '
820 R(6,T%/2+1)=D%
830 R(7,T%/2+1)=PR%
840 R(8,T%/2+1)=DS%
850 R(9,T%/2+1)=SG%
860 R(10,T%/2+1)=SC%
870 '
880 ' PRINT CURRENT PERIOD VALUES
890 '
900 CLS
910 PRINT "                              Year ";T%
920 PRINT
930 PRINT USING "          0. New orders from goods sector  #######";NG%
940 PRINT
950 PRINT USING "          1. Backlog of goods sector       #######";BG%
960 PRINT
970 PRINT USING "          2. Backlog of capital sector     #######";BC%
980 PRINT
990 PRINT USING "          3. Desired production            #######";DP%
1000 PRINT
1010 PRINT USING "          4. Capital stock                #######";PC%
1020 PRINT
1030 PRINT USING "          5. Depreciation                 #######";D%
1040 PRINT
1050 PRINT USING "          6. Production                   #######";PR%
1060 PRINT
1070 PRINT USING "          7. Fraction of demand satisfied ########%";DS%
1080 PRINT
1090 PRINT USING "          8. Ship. to goods sector        #######";SG%
1100 PRINT
1110 PRINT USING "          9. Ship. to capital sector      #######";SC%
1120 PRINT
1130 INPUT "          10. New orders for cap. sector";NC
1140 '
1150 ' CHECK FOR INVALID ENTRIES
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
```

APPENDIX E Continued

```
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%
1430 PRINT:PRINT:PRINT
1440 IF S%<=100 THEN PRINT "                      Congratulations, you should be manag
ing the economy!"
1450 IF 100<S% AND S%<=200 THEN PRINT "                                        Nice
job!"
1460 IF S%>200 THEN PRINT "                              Surf's up!"
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%=2500    '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 SECTO
R";
1700 LOCATE 25,1
1710 PRINT "P = PRODUCTION       S = CAPITAL STOCK      D = DESIRED PRODUCTION";
1720 '
1730 ' PRINT GRID
1740 '
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 '
1840 ' PRINT VERTICAL SCALE
1850 '
1860 FOR VLABEL%=1 TO 21 STEP 4
1870 LOCATE VLABEL%,1:PRINT (YM%/20)*(21-VLABEL%)
1880 NEXT VLABEL%
1890 '
1900 ' PRINT SCORE
1910 '
1920 LOCATE 1,68:PRINT "SCORE= ";S%
1930 '
1940 ' PLOT VARIABLES
1950 '
1960 FOR I=1 TO 11
1962 '
```

(continued)

APPENDIX E   Continued

```
1963 ' Don't print variables 2,3,6,8,9, or 10
1964 '
1970 IF I=2 OR I=3 OR I=6 OR I=8 OR I=9 OR I=10 THEN GOTO 2060
1980 FOR TPLOT=0 TO TIMEND STEP 2
1990 IF R(I,TPLOT/2+1)*20/YM%>20 THEN Y=1 ELSE IF R(I,TPLOT/2+1)*20/YM%<1
        THEN Y=21 ELSE Y=21-R(I,TPLOT/2+1)*20/YM%
2000 X=TPLOT+9
2010 LOCATE Y,X
2020 IF I=1 THEN PRINT "G"; ELSE IF I=11 THEN PRINT "C";
2030 IF I=4 THEN PRINT "D"; ELSE IF I=5 THEN PRINT "S"; ELSE IF I=7
        THEN PRINT "P";
2040 NEXT TPLOT
2050 INPUT Z$
2060 NEXT I
2070 '
2080 ' ask for replot
2090 '
2100 LOCATE 25,1:PRINT
2110 INPUT "Do you want to re-plot results on another scale <y/n>";PLOT$
2120 IF PLOT$<>"y" AND PLOT$<>"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 '
2170 ' PRINTOUT OF RESULTS
2180 '
2190 PRINT:INPUT "Do you want a printout of the results <y/n>";PR$
2200 IF PR$<>"y" AND PR$<>"Y" THEN GOTO 2440
2210 LPRINT "YEAR                              VARIABLE"
2220 LPRINT
2230 LPRINT "         0.    1.    2.    3.    4.    5.    6.    7.    8.    9.
 10."
2240 LPRINT "_____
____"
2250 LPRINT
2260 FOR T%=0 TO 70 STEP 2
2270 LPRINT USING " ##   ####  ####  ####  ####  ####  ####  ####  ####  ####  #
###  ####";T%,R(1,T%/2+1),R(2,T%/2+1),R(3,T%/2+1),R(4,T%/2+1),R(5,T%/2+1),R(6,T%
/2+1),R(7,T%/2+1),R(8,T%/2+1),R(9,T%/2+1),R(10,T%/2+1),R(11,T%/2+1)
2280 NEXT T%
2290 '
2300 ' print variable key
2310 '
2320 LPRINT:LPRINT "Score: ";S%:LPRINT
2330 LPRINT "0.   New orders from goods sector"
2340 LPRINT "1.   Backlog of unfilled orders from goods sector"
2350 LPRINT "2.   Backlog of unfilled orders from capital sector"
2360 LPRINT "3.   Desired production [=1+2]"
2370 LPRINT "4.   Production capacity"
2380 LPRINT "5.   Depreciation of capital stock"
2390 LPRINT "6.   Production [=MIN(3,4)]"
2400 LPRINT "7.   Fraction of demand satisfied [=6/3]"
2410 LPRINT "8.   Shipments to the goods sector [=7*1]"
2420 LPRINT "9.   Shipments to the capital sector [=6-8]"
2430 LPRINT "10.  New orders from capital sector"
2440 '
2450 ' quit check
2460 '
2470 INPUT "Type q to quit, <return> to plot or print again";Q$
2480 IF Q$<>"q" AND Q$<>"Q" THEN 2100
2490 END
```

APPENDIX F
Goods Sector Order Deck

450	450	500	500	500	500
500	500	500	500	500	500
500	500	500	500	500	500
500	500	500	500	500	500
500	500	500	500	500	500
500	500	500	500	500	500

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

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