MARKET GROWTH, COLLAPSE AND FAILURES TO LEARN FROM INTERACTIVE SIMULATION GAMES

M. Paich
Colorado College, Colorado Springs, USA

John D. Sterman
MIT System Dynamics Group, Sloan School of Management, Massachusetts Institute of Technology, USA

Key Words: Market growth, dynamic decision-making, learning, simulation, gaming, feedback, experimental economics

Contents

Summary

Market boom and collapse is a pervasive dynamic for new products. Word of mouth, marketing, and learning curve effects can fuel rapid growth, often leading to overcapacity, price war, and bankruptcy. Previous experiments suggest such dysfunctional behavior can be caused by systematic 'misperceptions of feedback,' where decision makers do not adequately account for critical feedbacks, time delays, and nonlinearities which condition system dynamics. However, prior studies often failed to vary the strength of these feedbacks as treatments, omitted market processes, and failed to allow for learning. In this research, first a simulation model of basic boom and bust dynamics for new products is built. Next, this model is used as a decision-making platform to test the "misperceptions of feedback" theory by varying the strength

of key feedback processes in the simulated market. In the experiments, subjects performed the task repeatedly, encouraging learning. Nevertheless, performance relative to potential is poor and is severely degraded when the feedback complexity of the environment is high, supporting the misperception of feedback hypothesis. The negative effects of feedback complexity on performance were not moderated by experience, even though average performance improved. Models of the subjects' decision-making heuristics are estimated; changes over trials in estimated cue weights explain why subjects improve on average but fail to gain insight into the dynamics of the system. Though conditions for learning are excellent, experience does not appear to mitigate the misperceptions of feedback or systematic dysfunction they cause in dynamic decision making tasks. We discuss implications for educational use of simulations and games.

1. Introduction

Market boom and collapse is a pervasive dynamic for new products. Sales of new products often grow rapidly as word of mouth, advertising, and falling prices attract new buyers. New producers tend to enter the market. But eventually the stock of potential purchasers is depleted and sales fall to an equilibrium determined by replacement needs. During the transition to replacement demand producers often suffer large losses due to excess capacity and falling prices, stimulating exit.

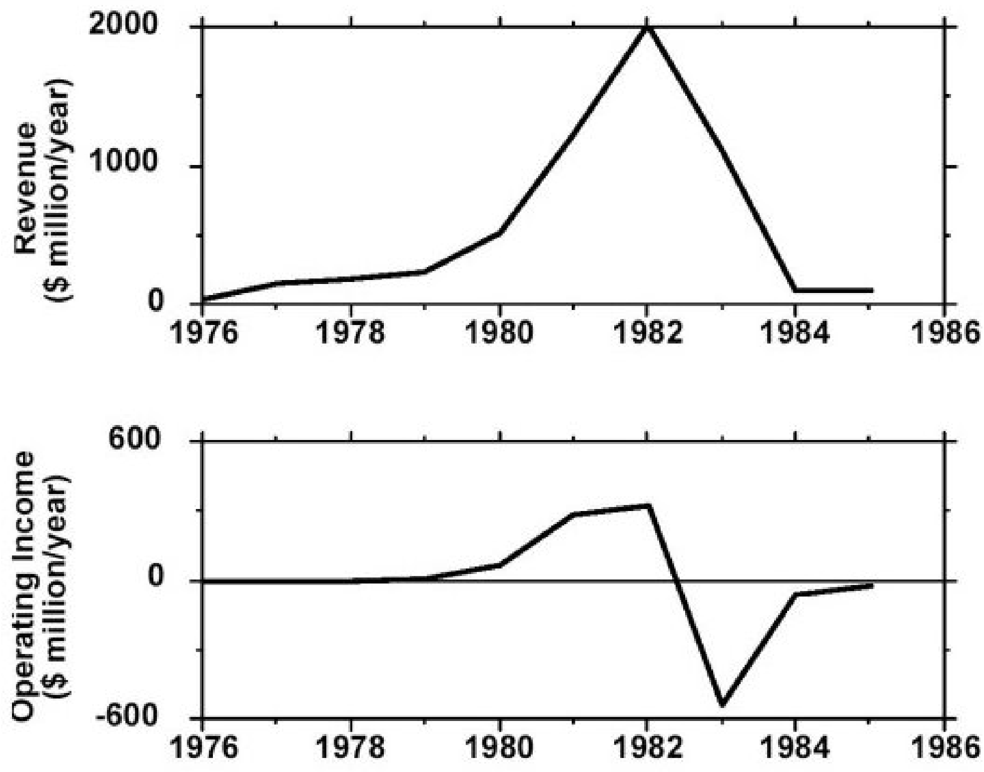

Figure 1. Boom and Bust: Sales and Operating Income of Atari, Inc.

Sources: 1976-1983: Warner Communications Annual Reports. 1984-1985: Atari, Inc. Company Reports; Investtext.

As a typical example, Figure 1 shows the sales and profits of Atari, the leader of the first wave of video games. Atari, then a division of Warner Communications, roughly doubled its sales each year, from $35 million in 1976 to over $2 billion in 1983. Operating profit reached $323 million in 1983. Yet within a year sales plummeted as both home and arcade markets became glutted. Atari lost $539 million in 1983, and was sold for just $160 million in debt, a 32 per cent equity stake, and no cash. Warner took an additional $592 million charge against 1984 earnings for losses related to the sale.

Porter (1980) describes this pattern of boom, bust, price war and shakeout as a generic feature of industrial dynamics:

"As a maturing industry adjusts to slower growth, the rate of capacity addition in the industry must slow down as well or overcapacity will occur. Thus companies' orientations toward adding capacity and personnel must fundamentally shift and be disassociated from the euphoria of the past.... These shifts in perspective rarely occur in maturing industries, and overshooting of industry capacity relative to demand is common. Overshooting leads to a period of overcapacity, accentuating the tendency during transition toward price warfare."

Boom and bust occurs in diverse industries. "Snow mobiles, hand calculators, tennis courts and equipment, and integrated circuits" are just a few examples cited by M. Porter. To these can be added VCRs and other consumer electronics, personal computers, toys and games, bicycles and chain saws, home furnishings, fiberglass sailboats and many others. This study explores the role of cognitive misperceptions and decision-making errors in the genesis and persistence of the boom and bust phenomenon.

The boom and bust dynamic exemplifies a dynamic decision making system. Decisions made today alter the environment, giving rise to information upon which tomorrow's decisions are based – the evolution of the system is strongly conditioned by the behavior of the decision makers. Recent studies show, with few exceptions, that decision-making in complex dynamic environments is poor relative to normative standards or even relative to simple heuristics, especially when decisions have indirect, delayed, nonlinear, and multiple feedback effects. Sterman argues that the mental models people use to guide their decisions are dynamically deficient. (See *Supply Chain Dynamics, the "Beer Distribution Game" and Misperceptions in Dynamic Decision Making*). People generally adopt an event-based, 'open-loop' view of causality, ignore feedback processes, fail to appreciate time delays between action and response and in the reporting of information, do not understand stocks and flows, and are insensitive to nonlinearities which may alter the strengths of different feedback loops as a system evolves. Sterman argues that such "misperceptions of feedback" cause systematically dysfunctional behavior in dynamically complex settings.

The term "misperceptions of feedback" covers more than simple perception. At the most basic level, poor performance can arise because decision makers do not attend to or perceive helpful outcome feedback. For example, real estate developers tend to start new projects when rents are high and prices are rising, and ignore the supply line of buildings under construction. By the time their projects are completed the market is glutted and prices have fallen. The information needed for high performance is available but not heeded: a misperception of (outcome) feedback. Why? Failure to utilize important cues can result from dynamically deficient mental models. Decision makers who do not understand feedback concepts are unlikely to perceive the feedback loops, time delays, and nonlinearities that create the system's dynamics and so may not see the relevance of a critical cue: a misperception of feedback structure. At a still deeper level, even given perfect information and complete knowledge of system structure people are not able to infer the resulting dynamics. To do so requires intuitive solution of high-order nonlinear differential equations, a task far exceeding human cognitive capabilities in all but the simplest systems.

Winston Churchill, commenting on the design of the House of Commons wrote: "We shape our buildings, and then our buildings shape us." Similarly, the different threads of the misperceptions of feedback phenomenon are themselves entwined in feedback loops. These interactions have not received sufficient attention in dynamic decision-making research. In many studies feedback complexity was not varied as an experimental treatment; other factors might have been responsible for subjects' poor performance. Market institutions, argued by many to provide incentives and means to overcome individual departures from rationality, have not been included in most studies of dynamic decision making. Many studies report the results of first trials in which subjects had little opportunity for learning. In others, subjects had little or no prior training or experience relevant to the task (fighting forest fires, treating disease, running a national economy or managing an ecosystem). While good arguments can be made that 'real life' is more like the first trial in such experiments than the last, the robustness of the misperception of feedback phenomenon to opportunities for learning has largely gone untested.

This study addresses many of the limitations of earlier work. The task – the management of a new product – is realistic and well matched to the interests of the management school subjects, most with several years of business experience. The experimental environment, based on an interactive simulation model, includes market forces. Powerful incentives are used to motivate performance. The misperception of feedback (MOF) hypothesis is tested directly by varying the strength of key feedback processes across experimental conditions. If subjects are prone to misperceptions of feedback, performance relative to potential should be systematically worse under high feedback complexity, since these feedbacks will produce consequences unaccounted for by subjects' mental models, and better in environments with low complexity, since these environments will more closely coincide with their mental models. Further, the subjects performed the task repeatedly, creating opportunities for learning which might improve performance. We describe the simulation model (the task), protocol, and results, analyze the nature of the learning process, and close with implications for educational use of simulations and games.

2. The Interactive Simulator: Managing a new product

The experimental task is based on an interactive computer model or "management flight simulator. The flight simulator embodies a model representing a firm, its market, and its competition (Figures 2, 3, and 4). Subjects manage a new product from launch through maturity, making price and capacity decisions each quarter year through a ten-year simulation. See Paich (1993) for documentation of the model, methods and results.

The game, revised for educational use with user's guide and instructor's manual, is available at Forio.com (www.forio.com/bandb.htm) .

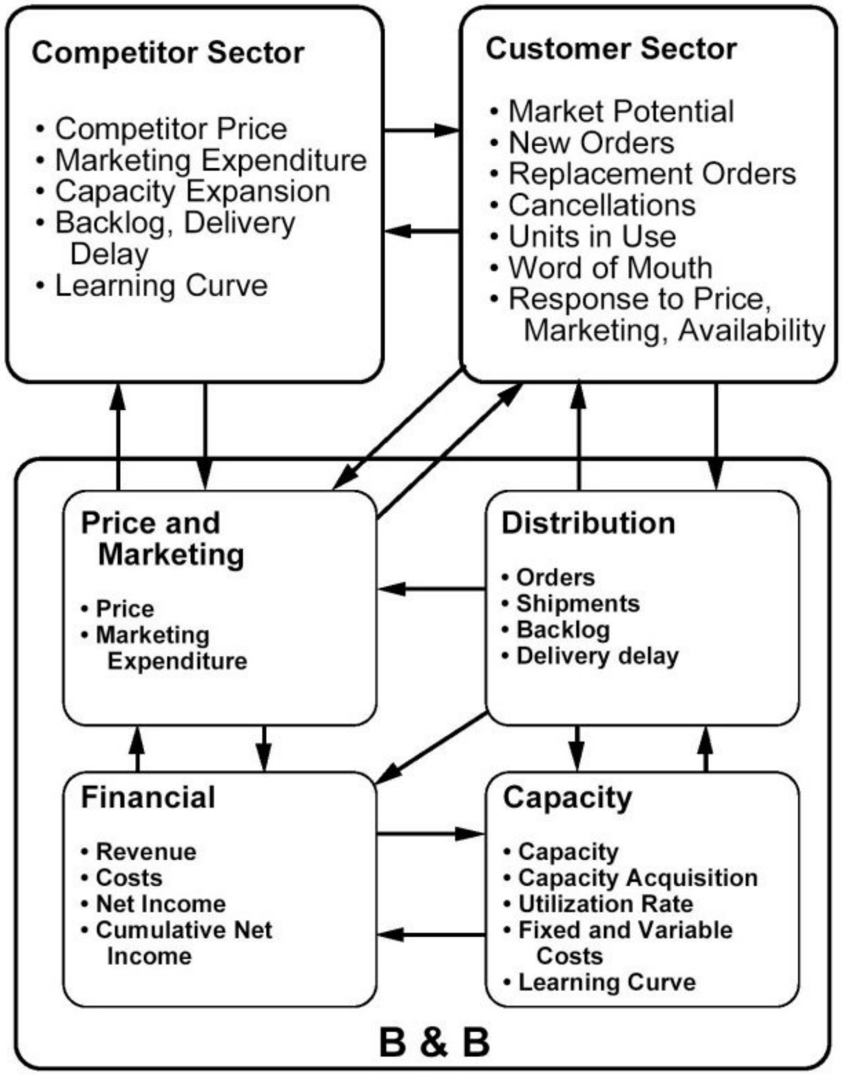

Figure 2. General sector diagram of the "Boom and Bust" management simulation game

2.1 Market Sector

The market model is based on well-known diffusion models in the tradition of Mahajan, Muller, and Bass (1990). (See *R&D, Technological Innovation and Diffusion* for a detailed discussion). The essence of these models is the feedback structure through which potential purchasers become aware of and choose to buy the product (Figure 3). Adoption increases the customer base, generating word of mouth which leads to additional sales (a positive feedback), but also depleting the pool of potential customers (a negative feedback). The customer base follows an s-shaped pattern, while sales rise exponentially, then peak and decline to the rate of replacement purchases as the market saturates. In reality additional feedbacks exist involving e.g. changes in technology, line extensions, cannibalization of sales by new generations of the product, network externalities, and so on. To keep the task manageable these effects are not treated. In equilibrium adoption equals replacement demand. Though not shown, many additional loops are created by the coupling of the market to the subjects' decisions.

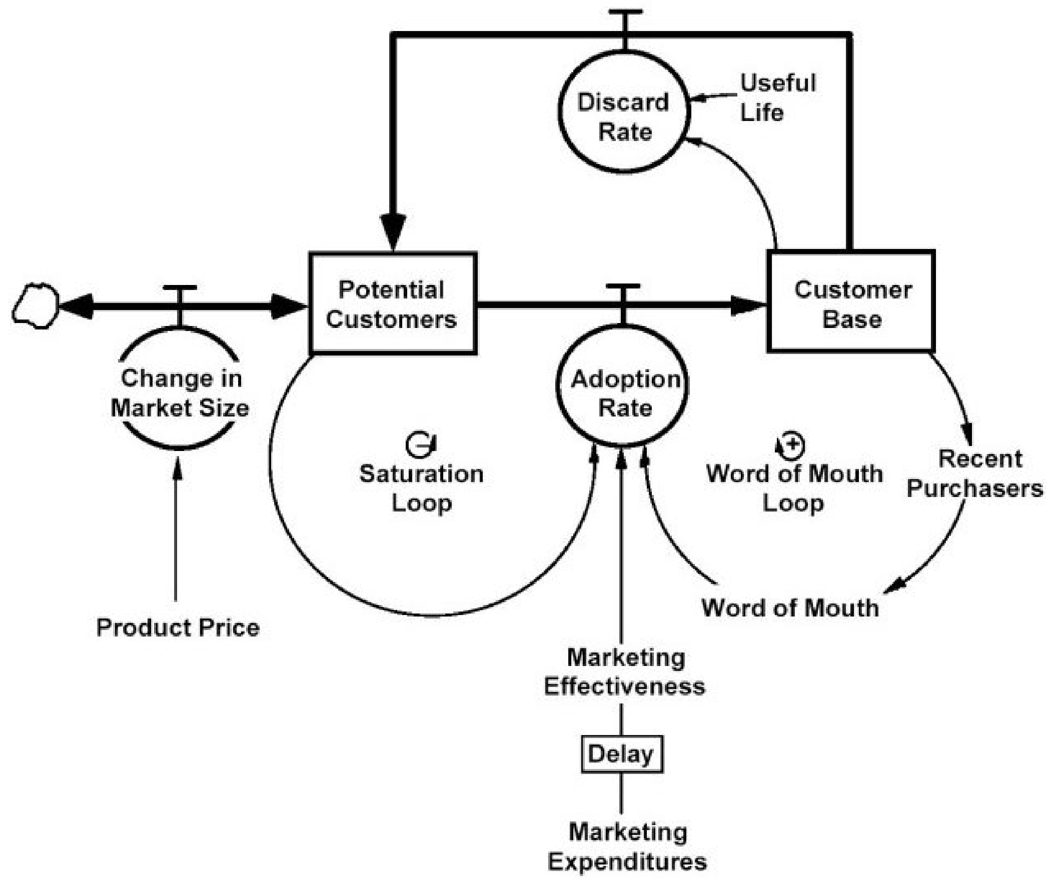

Figure 3. The stock-flow structure of the aggregate market

Key features of the market sector include:

- Product price affects the number of potential adopters. The elasticity of industry demand is less than unity, quite typical for many goods.
- The greater the aggregated marketing expenditures of the firm and the competition, the larger the fraction of potential customers who purchase each quarter. Diminishing returns set in for high marketing expenditure levels.
- Demand is also generated by word of mouth. Word of mouth is driven by recent purchasers (people who are still excited by the product and have not yet come to take it for granted). The strength of the word of mouth effect (the number of purchases generated per quarter by each recent purchaser) was a treatment variable in the experiment.
- A fraction of the customer base re-enters the market each quarter to replace worn or obsolete units. The repurchase fraction was a treatment variable in

the experiment.

- Total orders for the product are divided between the firm and the competition in proportion to the attractiveness of each product. Attractiveness depends on price, availability (measured by delivery delay), and marketing expenditure. (Figure 4) Firm demand is highly but not infinitely elastic – price is important to consumers but availability and marketing can differentiate the two products.

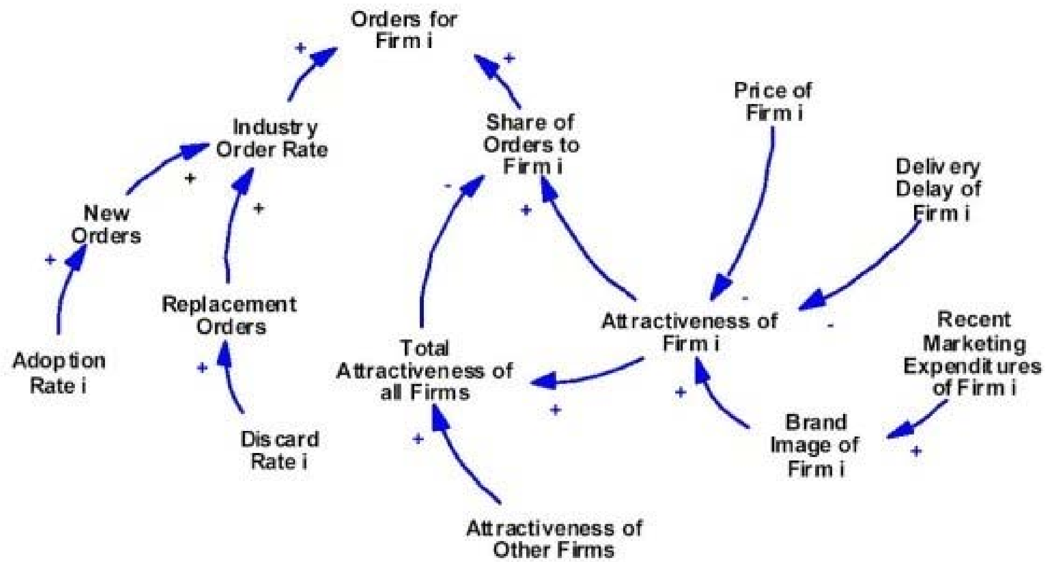

Figure 4. Causal Structure of the Market Sector

2.2. Firm Sector

While many diffusion models implicitly equate shipments with orders, the model here explicitly represents the supply side of the market. The key assumptions of the firm sector are:

- Product is built to order. Customer orders flow into a backlog until they are produced and shipped. Inventories are excluded; experimental evidence shows that inventories would substantially destabilize the system and make the player's task much harder. The firm will ship the current backlog within one period unless capacity is inadequate, in which case the backlog and delivery delay rise, reducing the attractiveness of the firm's product and the share of orders it receives.
- Subjects set a capacity target each quarter. Actual capacity adjusts to the target with a delay representing the time required to plan for, acquire, and ramp up new production facilities. Capacity adjustments follow a distributed lag with a mean of four quarters. Some investments can be realized sooner than four quarters (purchasing equipment), while some take longer (building new plant). For simplicity the delay is symmetrical in the case of capacity reduction.

- The firm benefits from a learning curve which reduces unit costs as cumulative production experience grows. A standard “80 per cent” learning curve is assumed – each doubling of cumulative production reduces unit variable costs by 20 per cent. The competitor’s learning curve has identical strength. Learning is assumed to be fully appropriable.
- Profit is revenue less total costs. Total costs consist of fixed and variable costs, marketing expenditures, and investment costs. Revenues are determined by the quantity shipped in the current quarter and the average price received for those units. Customers pay the price in effect when they booked their order, even if the price has changed in the interim.
- Fixed Costs are proportional to current capacity. Unit fixed costs are constant. Variable costs are proportional to output. Unit variable costs fall as cumulative production increases. Marketing expenditures are set to 5 per cent of revenues.
- Investment costs represent administrative, installation, training, and other costs of increasing capacity. Symmetric decommissioning costs are incurred whenever capacity is decreased. Investment costs are proportional to the magnitude of the rate of change of capacity.
- Subjects may lose as much money as they like without facing bankruptcy. The task is therefore more forgiving than reality since losses leading to bankruptcy in real life can in the game be offset by subsequent profits.

-
-
-

Bibliography

Brehmer, B. (1992). Dynamic Decision Making: Human Control of Complex Systems. Acta Psychologica 81, 211-241. [Psychology of dynamic decision making in complex dynamic settings, based on experimental evidence on various misperceptions of feedback and dynamic complexity].

Graham, A. K., Morecroft, J. D., Senge, P. M., & Sterman, J. D. (1992) Model Supported Case Studies for Management Education. *European Journal of Operational Research*, 59(1), 151-166. [Principles for effective use of simulation models and games to enhance case studies].

Hogarth, R. M., & Reder, M. W. (1987) *Rational Choice: The Contrast between Economics and Psychology*. Chicago: Univ. of Chicago Press. [A critical discussion of the theory of rational decision making, with special focus on various cognitive limitations that challenge the validity of the theory].

Hogarth, R. M., & Makridakis, S. (1981) The Value of Decision making in a Complex Environment: An Experimental Approach. *Management Science*, 27(1), 93-107. [Describes an experiment with a marketing simulation in which subjects could not distinguish between human and automated players].

Mahajan, V., E. Muller, and F. Bass (1990) New Product Diffusion Models in Marketing: A Review and Directions for Research. *Journal of Marketing* 54(1), 1-26. [Describes variety of product diffusion models and applications].

Morecroft, J. and J. Sterman (eds.) (1992) Modeling for Learning. Special issue of *European Journal of Operational Research*. 59, 1 (May). [Collection of papers covering use of models and management flight simulators to enhance learning and decision making by managers. Also published as the book Modeling for Learning Organizations, Portland OR, Productivity Press, 1994].

Mosekilde, E., E. Larsen, J. Sterman, & J. Thomsen (1992) Nonlinear Mode-Interaction in the Macroeconomy. In Feichtinger, G. (Ed.), *Annals of Operations Research* 37. [Examines the entrainment of individual firms into macroeconomic cycles.

Paich, M. (1992) PhD Thesis, MIT Sloan School of Management. [Describes the experiment reported here in detail].

Porter, M. (1980) *Competitive Strategy*. New York: Free Press. [Basic text on industry strategy].

Richardson, G. and J. Rohrbaugh (1990) Decision Making in Dynamic Environments: Exploring Judgments in a System Dynamics Model-Based Game, in Borcherding, K. et al. (eds.) *Contemporary Issues in Decision Making*. Amsterdam: North Holland, 463-472. [Reports a dynamic decision making task].

Senge, P., & Sterman, J. D. (1992) Systems Thinking and Organizational Learning: Acting Locally and Thinking Globally in the Organization of the Future. In Kochan, T. & Useem, M. (Eds.), *Transforming Organizations* Oxford: Oxford University Press, 353-371. [Discusses the use of models and simulations to enhance organizational decision making, with a case study describing how such an approach assisted an insurance company].

Sterman, J. D. (1989a) Misperceptions of Feedback in Dynamic Decision Making. *Organizational Behavior and Human Decision Processes*, 43(3), 301-335. [Reports an experiment with a dynamic system in which subjects exhibit multiple misperceptions of feedback].

Zarnowitz, V. (1985) Recent Work on Business Cycles in Historical Perspective: A Review of Theories and Evidence, *Journal of Economic Literature*. 23, 523-80. [Review of business cycle theory].

Biographical Sketches

John D. Sterman is the Jay W. Forrester Professor of Management at the MIT Sloan School of Management and Director of MIT's System Dynamics Group. His research includes systems thinking and organizational learning, computer simulation of corporate strategy, and the theory of nonlinear dynamics. Author of many scholarly and popular articles on the challenges and opportunities facing organizations today, including the book *Modeling for Organizational Learning*, and the award-winning textbook *Business Dynamics*, he has presented his work before corporate, financial, and government audiences worldwide. Prof. Sterman's research centers on improving managerial decision making in complex systems. He has pioneered the development of "management flight simulators" of corporate and economic systems. These flight simulators are now used by corporations and universities around the world. His recent research ranges from the dynamics of organizational change and the implementation of sustainable improvement programs to experimental studies assessing public understanding of global climate change. Prof. Sterman has twice been awarded the Jay W. Forrester Prize for the best published work in system dynamics, won the 2001 Accenture Award for the best paper of the year published in the *California Management Review* (with Nelson Repenning), has five times won awards for teaching excellence from the students of the Sloan School, and was named one of the Sloan School's "Outstanding Faculty" by the 2001 *Business Week Guide to the Best Business Schools*. He has been featured on public television's *News Hour*, National Public Radio's *Marketplace*, CBC television, *Fortune*, the *Financial Times*, *Business Week*; and many other newspapers and journals for his research work and innovative use of interactive simulations in management education and corporate problem solving.

Mark Paich has over 25 years of experience in building dynamic business models. He has a BA in political economy from Colorado College, an MA in economics from the University of Colorado, and a PHD in system dynamics from MIT. Mark's specialty is the dynamics of new industry creation and he has worked extensively in telematics (GM Onstar system), Digital radio (XM and WorldSpace), fuel cell and hybrid vehicles (GM), and various pharmaceutical products. Selected clients include General Motors, Eli Lilly, Johnson & Johnson, and the Department of Defense. Mark was senior specialist at McKinsey & Co. from 1998-2001. A number of his consulting projects are described in John Sterman's book Business Dynamics.
Mark taught economics, finance, and business strategy at Colorado College for 25 years and is a frequent

guest lecturer at MIT's Sloan School of Management. In 2000, Mark and his co-authors from GM placed second in the 2001 Edelman competition for the best work in operations research and management science.