

## CHAOS THEORY AND STRATEGY: THEORY, APPLICATION, AND MANAGERIAL IMPLICATIONS

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*This paper argues that chaos theory provides a useful theoretical framework for understanding the dynamic evolution of industries and the complex interactions among industry actors. It is argued that industries can be conceptualized and modeled as complex, dynamic systems, which exhibit both unpredictability and underlying order. The relevance of chaos theory for strategy is discussed, and a number of managerial implications are suggested. To illustrate the application of chaos theory, a simulation model is presented that depicts the interactions between a manufacturer of computers, its suppliers, and its market. The results of the simulation demonstrate how managers might underestimate the costs of international production. The paper concludes that, by understanding industries as complex systems, managers can improve decision making and search for innovative solutions.*

### INTRODUCTION

One of the enduring problems facing the field of strategic management is the lack of theoretical tools available to describe and predict the behavior of firms and industries. For example, even if we know that oligopolistic industries are likely to experience periods of stability alternating with periods of intense competition, we do not know when they will occur or what will be the outcome. Similarly, it is almost impossible to predict the impact of the advent of a new competitor or technology in an industry. The fundamental problem is that industries evolve in a dynamic way over time as a result of complex interactions among firms, government, labor, consumers, financial institutions, and other elements of the environment. Not only does industry structure influence firm behavior, but

firm behavior in turn can alter the structure of an industry and the contours of competition. Existing theoretical models, however, tend to assume relatively simple linear relationships without feedback. Indeed, many strategic theories attempt to classify firms and industries and to describe appropriate strategies for each class; examples include the Boston Consulting Group matrix for resource allocation and Bartlett's classification of international strategies (Bartlett and Ghoshal, 1989). Although these models are based on recurrent patterns that we recognize in the real world, there are usually far too many exceptions for the models to have much predictive value.

Chaos theory, which is the study of nonlinear dynamic systems, promises to be a useful conceptual framework that reconciles the essential unpredictability of industries with the emergence of distinctive patterns (Cartwright, 1991). Although chaos theory was originally developed in the context of the physical sciences, Radzicki (1990) and Butler (1990) amongst others have

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noted that social, ecological, and economic systems also tend to be characterized by nonlinear relationships and complex interactions that evolve dynamically over time. This recognition has led to a surge of interest in applying chaos theory to a number of fields, including ecology (Kauffman, 1991), medicine (Goldberger, Rigney and West, 1990) international relations (Mayer-Kress and Grossman, 1989), and economics (Baumol and Benhabib, 1989; Kelsey, 1988).<sup>1</sup> Despite the apparent applicability of chaos theory to the field of business strategy, there has been surprisingly little work in this area.

This paper introduces readers to chaos theory, and discusses its relevance to the social sciences in general and to aspects of strategy in particular, including planning and forecasting, and the impact of change on firms and industries. The application of chaos theory to a business situation is illustrated using a simulation model of an international supply chain. The model, which is based on the author's research into the supply chain of a California-based computer company, depicts the complex interactions between the firm, its suppliers, and its markets. The simulation results illustrate the managerial implications of applying chaos theory to strategic management. The model demonstrates how small disruptions to the supply chain interact to make the chain highly volatile, imposing significant costs on the organization. Although forecasting is very difficult in the supply chain, distinct patterns emerge which are useful for managers. The simulation also shows that by understanding the supply chain as a complex dynamic system, it is possible to identify managerial approaches that lower the cost of operating the supply chain.

## AN INTRODUCTION TO CHAOS THEORY

Chaos theory is the study of complex, nonlinear, dynamic systems. The field was pioneered by Lorenz (1963), who was studying the dynamics of turbulent flow in fluids. Although we all recognize the swirls and vortices that characterize turbulent flow, the complexities of turbulent flow

have confounded mathematicians for years. A similar problem afflicts someone who is trying to calculate the path of an object in the gravitational pull of two or more bodies. While we can use simple Newtonian equations to predict the orbits of planets around the sun with a high degree of accuracy, the mathematics involved in the case of two or more 'suns' become intractable. The problem can be illustrated on a terrestrial level by observing the motion of a simple toy, a metal ball suspended over two or more magnets. The ball will trace a series of patterns that never exactly repeat themselves, and yet are not totally random.

The paradox here is that the motion of the metal ball is driven by the same Newtonian equations as the well understood case of a single gravitational attractor. If we knew precisely the original location, speed, and direction of the ball, we ought to be able to predict its path with a reasonable degree of accuracy. How is it that deterministic systems can give rise to unpredictability? The explanation is that tiny variations in the motion of the ball are magnified every time it swings by one of the magnets. It is a combination of this divergence and the repeated interactions that give rise to 'chaotic' behavior. Mathematically, chaotic systems are represented by differential equations that cannot be solved, so that we are unable to calculate the state of the system at a specific future time 't'.

At the limit, chaotic systems can become truly random. A toss of a coin or the roll of a die are, in theory, deterministic systems, but yield more or less random outcomes. Not only is it impossible to toss a coin twice in exactly the same way, but on each toss the coin is subject to slightly different air currents, themselves a result of turbulent air flow (Ford, 1983).

To overcome the problem of intractable differential equations, researchers usually model systems as discrete difference equations, which specify what the state of the system will be at time 't+1' given the state of the system at time 't.' Computer simulations can then be used to see how the system evolves over time.

One of the major achievements of chaos theory is its ability to demonstrate how a simple set of deterministic relationships can produce patterned yet unpredictable outcomes. Chaotic systems never return to the same exact state, yet the outcomes are bounded and create patterns that

<sup>1</sup> See also special issues of *Journal of Economic Theory*, 40(1), 1986, and *Journal of Economic Behavior and Organization*, 8(3), 1987.

embody mathematical constants (Feigenbaum, 1983). It is the promise of finding a fundamental order and structure behind complex events that probably explains the great interest chaos theory has generated in so many fields.

### Chaos theory and the social sciences

Proponents of chaos theory enthusiastically see signs of it everywhere, pointing to the ubiquity of complex, dynamic systems in the social world and the resemblance between patterns generated by simulated nonlinear systems and real time series of stock exchange or commodity prices. From a theoretical perspective, chaos theory is congruous with the postmodern paradigm, which questions deterministic positivism as it acknowledges the complexity and diversity of experience. While postmodernism has had a profound influence on many areas of social science and the humanities, it has been neglected by organization theorists until very recently (Hassard and Parker, 1993).

Despite its attractions, the application of chaos theory to the social sciences is still in its infancy, and there are those who think that expectations are too high (Baumol and Benhabib, 1989). Although real life phenomena may resemble the patterns generated by simple nonlinear systems, that does not mean that we can easily model and forecast these phenomena; it is almost impossible to take a set of data and determine the system of relationships that generates it (Butler, 1990). In fact, there is considerable debate in the economics and finance literature about how one tests a data series to determine if it is chaotic or simply subject to random influences (Brock and Malliaris, 1989; Hsieh, 1991). Moreover, it is important to recognize that many systems are not chaotic, and that systems can transition between chaotic and nonchaotic states. Chaos theory is perhaps better seen as an extension of systems theory (Katz and Kahn, 1966; Thompson, 1967) into the realm of nonlinear dynamics rather than as a total paradigm shift.

It is possible that the application of chaos theory to social science has been constrained by the fact that it has developed in relation to physical systems, without taking into account fundamental differences between physical and social science. In the social world, outcomes often

reflect very complex underlying relationships that include the interaction of several potentially chaotic systems; crop prices, for example, are influenced by the interaction of economic and weather systems. The search for a simple set of equations to explain complex phenomena may be a futile attempt to construct grand 'meta-theory,' a project that is rejected in the postmodern paradigm. The application presented here uses a different approach; field study research is used to derive a set of relationships among variables and the influence of external systems is modeled probabilistically, a method suggested by Kelsey (1988).

Social and physical systems also differ in the source of unpredictability. In the physical world, unpredictability arises due to many iterations, nonlinearity, and our inability to define starting conditions with infinite precision. In the social world, far less accuracy is possible in defining starting conditions, and the specification of the system structure itself is much less precise.

A final difference is that physical systems are shaped by unchanging natural laws, whereas social systems are subject to intervention by individuals and organizations. Investigations of economic time series by chaos theorists have usually assumed that relationships among economic actors are fixed over time. In reality, methods of stabilizing the economy have changed from the use of the gold standard and balanced budgets to Keynesian demand management and, later, to monetarist controls. Human agency can alter the parameters and very structures of social systems, and it is perhaps unrealistically ambitious to think that the effects of such intervention can be endogenized in chaotic models.<sup>2</sup> Nevertheless, chaotic models can be used to suggest ways that people might intervene to achieve certain goals. The application presented here, for example, shows how management can reduce the volatility of the supply chain to improve performance.

<sup>2</sup> To some extent, the distinction between endogenous and exogenous variables in a model is one of convenience; a factor that is exogenous in a simple model might become endogenous in a more complex and comprehensive one. Exogenous factors can be included as random variables in chaotic systems for modeling purposes (Kelsey, 1988).