Exploring Spatio-Temporal Dynamics in Economic Exchange: A Dynamic Modeling Approach

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Introduction

Economics is a discipline rich in models designed to elucidate the behavior of potentially complex economic processes. The reduction of complex processes to analytically solvable models, however, shifted focus away from the spatio-temporal dynamics representative of economic processes, and excluded to a significant extent experimentation from the repertoire used to understand these processes (Allen 1988, Ruth 1993).

In the illustrations below, special attention is given to three issues that are found at the sidelines of traditional economic analysis (Hannon and Ruth 1994, Ruth and Hannon, in press). The first of these issues concerns the dynamics of economic systems on their way to equilibrium points. The second is the spatial context within which economic activity takes place. The third are temporal and spatial *discontinuities* of economic processes.

Three models of simple exchange economies are developed that illustrate the role of spatio-temporal dynamics and the contribution dynamic modeling can make to the understanding of economic processes. Conclusions are drawn for new ways of exploring the fundamental principles that underlie potentially complex economic processes, for model development and experimentation, and for teaching economics.

Models

Dynamic Edgeworth Model

The first of the models of economic exchange is based on a traditional economic model of two players who engage in barter trade with each other. In contrast to the traditional Edgeworth model dealing with the two-player barter economy, it is assumed that the utility U derived from two goods X and Y that are exchanged between players A and B is a function of the goods that have been accumulated at a given time period T:

$$U_i = \left(\int_0^T X_i dt \right)^{\alpha_i} \left(\int_0^T Y_i dt \right)^{\beta_i}, \quad \alpha_i + \beta_i \leq 1 \ \forall \ i = A, B$$

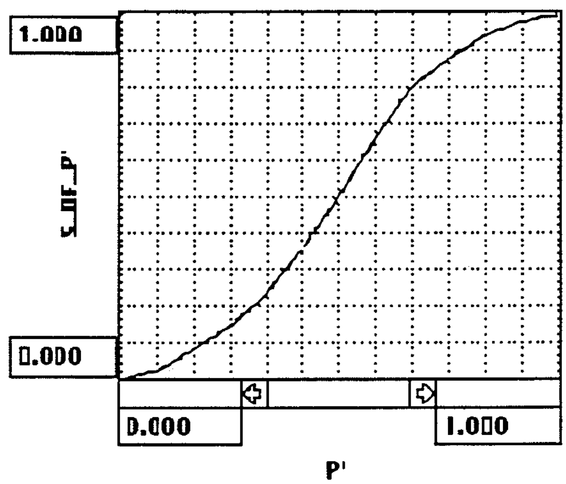
Exchange quantities per time period are assumed to be proportional to the change in utility. Given these simplified assumptions, several cases are explore—including envy and altruism. It is shown that even in the absence of discounting, the assumptions on the players' preferences influence the speed at which an equilibrium is reached.

Discontinuities and Chaos

The second model captures dynamics of supply-demand interactions on markets and exhibits potentially chaotic behavior. The demand curve is a linear function of observed prices P(t)

$$Q(t) = D(P(t)) = A - B*P(t)$$

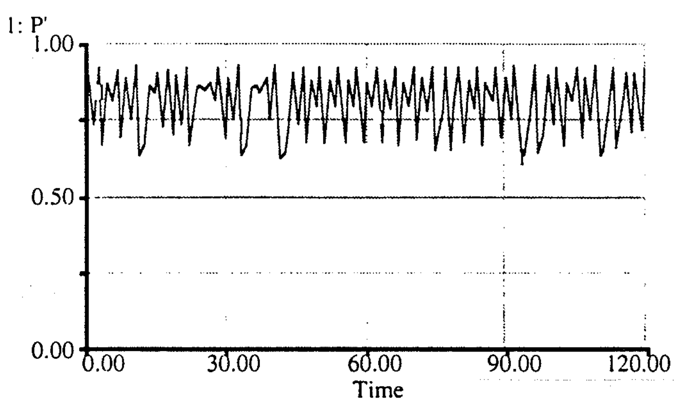
The supply curve, in contrast, is the nonlinear function in expected prices P'(t) shown in the figure to the right. Price expectations P'(t+1) are formed as a linear combination of actual and expected prices:

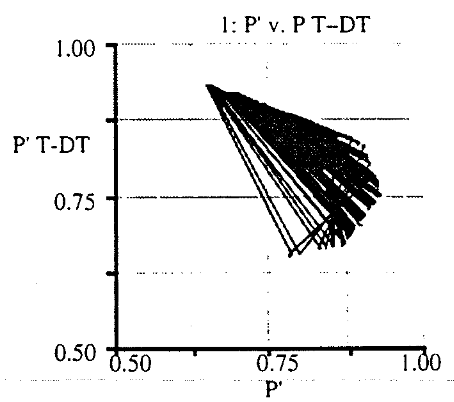


$$P'(t+1) = (1-W) * P'(t) + W * P(t)$$

The following price path results:

$$P'(t+1) = (1-W) * P'(t) - \frac{A*W}{B} + W * \frac{S(P(t))}{B}$$





Alternative values of W result in damped oscillations, oscillations with one, two and higher periods, and ultimately chaos which is shown in the two figures above. Despite the simplicity in its assumptions, the model exhibits a wide range of behaviors that vividly

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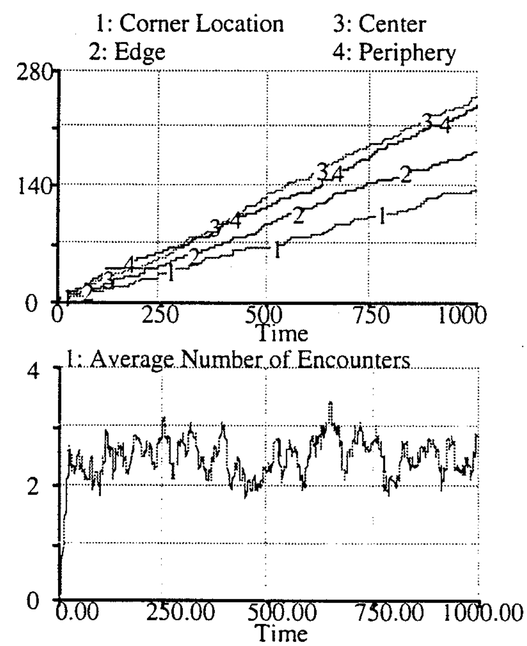
contrast the traditional equilibrium notion, and invites experimentation into the analysis of market mechanisms. The number of questions that can be answered through this experimental approach is large, and so is the opportunity to use dynamic modeling to explore the behavior of systems of economic exchange.

Spatio-Temporal Dynamics in Economic Exchange

The third model demonstrates the use of cellular automata (von Neumann 1966) to capture economic system behavior in space and time. It does not assume that a single market exists, nor that the players have perfect knowledge who the potential trading partners are, where they are located and at what price they are willing to exchange their goods and services. Thus, this model describes an extreme case of market exchange to provide a contrast to the traditional models.



Players in the core of the economic landscape enjoy a higher likelihood of encounters with their neighbors. As expected, the number of encounters declines towards the periphery. The average number of encounters per time period follows a random walk. If trading partners retain knowledge of their past trading partners and preferentially seek out those partners with whom they happened to "meet" more frequently, the system tends to settle down in the long-run. The case shown here of zero knowledge retention and of exchange with only close neighbors is a special case of high discounting in space and time—assumptions that can be easily relaxed to investigate the dynamics of a large set of real-world spatial exchange processes.

Conclusions

Models are the basis of every-day life decision making and are an integral part of any scientific inquiry. They provide the basis for assembling, communicating and evaluating information, for assessing cause-effect relationships and for generating knowledge. The three models developed in this paper provide examples of a specific type of models—causal models developed to illucidate the dynamics of economic exchange processes. The first of these models is based on a traditional economic model of two players who engage in barter trade with each other. Even in the absence of discounting, the assumptions on the players preferences are found to influence the speed at which an equilibrium is reached. The second model captures dynamics of supply-demand interactions on markets with price expectations and exhibits potentially chaotic behavior. The third deals with economic exchange that is not coordinated by markets or contractual agreements. This model demonstrates the use of cellular automata to capture system behavior in space and time.

Each of the models described in the paper have been designed to capture dynamics of economic exchange. Each of them tells a story that enriches our intuition and knowledge of economic exchange processes irrespective of the precise numerical values generated by these models. They are heuristic devices that help us visualize the implications of behavioral assumptions on the *dynamics* of an economic system.

Developing and running these models has learning as a desired result, rather than numeric predictions. The former is a prerequisite for the latter as it encompasses the generation of knowledge—rather than derived facts; it is also an essential prerequisite for decision-making in an ever-changing world. The dynamic modeling approach, and the models used here to illustrate it, is gradually beginning to open the doors for experimentation in economics, to reduce the use of mechanistic assumptions and models in what is in essence a behavioral science, and to instill in a new generation of decision makers an appreciation of potentially complex spatio-temporal system dynamics.

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