The Interactions-Based Approach to Socioeconomic Behavior

Lawrence E. Blume
Department of Economics, Cornell University

Steven N. Durlauf
Department of Economics, University of Wisconsin

This Draft: January 2000

Forthcoming, *Social Dynamics*, S. Durlauf and H. P. Young eds., MIT and Brookings Institution Press. The National Science Foundation, John D. and Catherine T. MacArthur Foundation and Santa Fe Institute have supported this work. We thank William Brock, Donald Hester, Andros Kourtellos, Jonathan Parker, Kenneth West, Christopher Wheeler, and Peyton Young for helpful comments.

1. Introduction

The last decade has seen the emergence of a growing body of research using interactions-based methods in economics.[1] This work has developed both in terms of abstract theory (Blume (1993,1995,1997), Brock (1993), Brock and Durlauf (1999a,b), Durlauf (1997b), Morris (1996), Young (1993,1998)) and in terms of substantive applications.[2] Despite these advances, the use of interactions-based methods in economic analysis is still in its infancy. Further, considerable skepticism exists in many quarters as to the utility of these methods. The purpose of this essay is to provide a perspective on why interactions-based models represent a natural and powerful language for studying economic and related phenomena. Our intended audience in this discussion consists of both fellow economists as well as the broader community of social scientists.

Any argument that economists should concern themselves with a particular modelling approach runs the danger of looking for economic problems to rationalize the use of the tools. This danger is real, as is illustrated by the now-irrelevant work applying catastrophe theory to economics. Recognizing this danger, we nevertheless feel that interactions-based methods embody an extremely broad perspective on economics, one which finds ready application across many specific questions. Further, these

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[1] Schelling (1971) and Föllmer (1974) are important forerunners of this recent literature.

[2] These applications include the location and concentration of economic activity (Arthur (1987) and Krugman (1996), the adoption of new technologies (Arthur (1989)), asset price behavior (Brock (1997)), the emergence of communication and trading patterns (Ioannides (1990), Kirman (1983), Kelly (1997)), income inequality (Durlauf (1996a,b)) social pathologies such as out of wedlock births and crime (Brock and Durlauf (1999a), Glaeser, Sacerdote, Scheinkman (1996)), evolution of political parties (Kollman, Miller, Page (1992)), expectation formation (Brock and Hommes (1997)), aggregate growth and business cycles (Bak, Chen, Scheinkman, and Woodford (1993), Blume (1994), and Durlauf (1993)), among many others.

approaches are, we will argue, a methodology which can expand the social and psychological richness of formal economic modelling.

Our interest in interactions-based modelling stems from the belief that a common general structure underlies such apparently different problems as the level of out-of-wedlock births, the agglomeration of firms in particular regions and the diffusion of technologies. In each case, the basic phenomenon of interest is the collective behavior of a group of interacting, heterogeneous agents. Our claim is that interactions-based approaches provide a powerful way of understanding these phenomena.

In terms of substantive departures from other types of economic modelling, the interactions-based approach focuses on direct interdependences between economic actors rather than those indirect interdependences which arise through the joint participation of economic actors in a set of markets. Indeed, the various types of interactions which have been the primary object of study in this literature have generally been ones that are not mediated by market structures. Standard examples include peer group and role models effects or interdependent preferences. The sorts of insights found in Clark's (1982) classic work on the ghetto, which relate direct group effects to individual outcomes, are precisely those which the interactions-based approach attempts to formally model.

We emphasize the role of these models in studying heterogeneous populations for three reasons. First, many of the questions we wish to examine concern the distributions of types of behaviors across populations. The ability of these models to formally characterize feedbacks between individuals within a population as well as characterize the aggregate implications of these feedbacks thus make them a natural way of addressing such questions. A key substantive idea of the interactions-based approach is that a precise mathematical characterization can be made which maps various interaction structures to associated population-wide distributions. Second, many economic environments of interest embody imperfections (relative to the baseline environment of general equilibrium theory) such as incomplete markets or asymmetric information which most sensibly occur in the presence of heterogeneity. Interactions models, which are driven by complementarities and spillovers between agents, thus allow for the analysis of these market imperfections in heterogeneous agent contexts. Third, models with heterogeneous agents often have very different properties from their homogeneous agent counterparts. This is trivially obvious in some cases; for example, incompleteness of markets in an exchange economy may not matter if agents possess identical endowments. A deeper example is found in the work of Grandmont (1989) and Hildenbrand (1994) who give some sufficient conditions on individual heterogeneity which produce an aggregate law of demand (roughly speaking, a negative relationship between price and aggregate demand).

One interesting feature of interactions-based models, which we shall only focus on indirectly, is that they incorporate many of the cases in which complexity theory has been applied to economics. As the literature on socioeconomic interactions becomes better developed, we believe that mathematics of complexity, with its emphasis on phenomena such as self-similarity and scaling laws, will prove to be of substantial value to social scientists.

In making a case for the importance of interactions-based analysis in economics, we proceed as follows. Section 2 describes a framework which illustrates how an interactions-based approach can facilitate different types of economic modelling. This framework is designed to illustrate how interactions-based approaches can complement conventional modelling strategies. Section 3 describes two senses in which interactions models can facilitate the development of substantive social science insights. Section 4 discusses how the interactions-based approach complements general equilibrium theory. General equilibrium theory, embodied by the Arrow-Debreu model and its many extensions, constitutes the bedrock of much economic analysis. It is therefore important to understand in what sense the analysis of interactions facilitates either extensions of or alternatives to the general equilibrium paradigm. Section 5 discusses what implications interactions-based modelling holds for methodological individualism and reductionism in economics. Section 6 suggests some areas where interactions-based modelling may be of value. Section 7 provides summary and conclusions.

2. The basic structure of interactions-based models

i. Interdependent decisionmaking

The underlying logic of interactions models is straightforward. The object of a typical exercise using these models is to understand the behavior of a population of economic actors rather than that of a single agent. The focus of the analysis is on the role of externalities across actors in determining the population-wide behavior. These externalities are in turn the source of interactions. These interactions are taken to be direct. The decision problem of any one actor takes as parameters the decisions of other actors. In examining the collective behavior, the interactions approach treats aggregate socioeconomic behavior as a statistical regularity of the collection of individual decisions as they are determined through the interactions and idiosyncratic characteristics of the agents. In treating aggregate behavior as a statistical regularity, it turns out that individual behavior need not be as tightly modelled as it is in traditional economic models. Individual choice is guided by payoffs, but has a random component. For this example, the randomness can be attributed to individual-specific variables not observed by the modeller, or to some form of bounded rationality; none of our substantive conclusions will depend on the interpretation.

Random choice models have been of longstanding importance in both theoretical and empirical economics, and the analysis of externalities is certainly not new. However, the combination of the two along with an analytical focus on population behavior gives rise to new and interesting phenomena. These systems are highly nonlinear and have multiple steady states, so that the individual decision rules do not, by themselves, uniquely characterize the population as a whole. A system's response to shocks can further be quite complex.

Interactions models typically specify an explicit probability measure characterizing individual behavior conditional on exogenous (to the individual) characteristics which can be either common to all members of the population or individual-specific, and an interaction structure which specifies who affects whom. The microeconomic structure of the environment under consideration determines these individual-level conditional probabilities. The goal of the analysis is to characterize a joint probability measure over all agents in the population that is compatible with these conditional probability measures. This sort of question is standard in the mathematics of random fields and complexity.

To fix ideas, consider first a population of actors facing identical choices, denoted as ω_i, in which no externalities are present. Conditional on a set of exogenous individual-specific characteristics X_i, the contemporaneous behavior of each agent is independent of the behavior of the rest of the population. Thus the joint probability measure characterizing population choices may be factored, so that

$$Prob(\omega_1,\ldots,\omega_I \mid X_1,\ldots X_I) = \prod_{i=1}^{I} Prob(\omega_i \mid X_i) \tag{1}$$

Conditional independence is sufficient to allow one to characterize aggregate behavior of the population through one of the many laws of large numbers. Under very weak conditions, one has

$$I^{-1}\sum_{i=1}^{I}\omega_i \approx I^{-1}\sum_{i=1}^{I}E(\omega_i \mid X_i) \tag{2}$$

for large I (when these expectations exist).

When individual decisions are contemporaneously interdependent, however, the factorization in eq. (1) may fail to exist. Further, the presence of cross-agent externalities introduces a potential strategic element into decisionmaking which needs to be incorporated into the specification of the model. One modelling strategy which preserves the factorization is to introduce a set of variables Z into the model which are endogenously determined by the system, yet preserve the conditional independence of the individual choices. This means that we can model each decision as obeying

$$Prob(\omega_i \mid X_i, Z) \tag{3}$$

and model the joint conditional probability measure of all decisions as

$$Prob(\omega_1,\ldots,\omega_I \mid X_1,\ldots,X_I,Z) = \prod_{i=1}^{I} Prob(\omega_i \mid X_i, Z) \tag{4}$$

In order to solve for the behavior of the population as a whole, it is of course necessary to specify how Z is determined; and such a specification can only be justified by the particular environment under study. For instance, Z may represent the expected value of the average choice in the population. Such an assumption is relatively appealing when one is working with a large population, as occurs when one is asking a question such as how the average smoking behavior of all teenagers influences individual smoking decisions.

From the perspective of analyzing aggregate behavior, what is important is that for any common belief about this average choice, one can compute the mathematical expectation of the average choice. By requiring that the common belief about the average choice in the population equal this mathematical expectation, one can arrive at a model of choice based on the self-consistency condition that $Z = I^{-1}\sum_{i=1}^{I} E_i(\omega_i)$. This type of argument, which was originally developed to solve rational expectations models, will be used to solve some examples below.

Operationally, interactions-based approaches are most useful when the underlying properties of a socioeconomic environment depend critically on direct connections between agents. Interactions play an essential role in models that describe interdependent binary decisions such as dropping out of school or committing a crime (Glaeser, Sacerdote, and Scheinkman (1996), Brock and Durlauf (1999a)), imitation effects in consumption (Bell (1995)), bilateral trade and economic specialization (Kelly (1997)), and local technological complementarities and economic development (Durlauf (1993)). While the particular substantive models differ, the dependencies among agents can be conceptualized and analyzed using formulations like those described by eqs. (1)-(3).

Again, modelling interdependent decisions in economics is not new per se. Modelling interrelationships which are direct rather than determined via markets is standard in game theory. What is important about interactions-based approaches is that the reasoning from probabilistic descriptions of individual behavior to population-wide aggregates provides a way to explicitly understand the emergence of collective properties in an economy.

ii. A baseline model with interdependences

To see how interactions-based methods can provide concrete insights, we provide some examples based on ideas in Brock (1993), Blume (1993,1997), Brock and Durlauf (1999a) and Durlauf (1997), each of which studies binary choice decisions in the presence of social interactions. These examples illustrate how a choice-based model with standard economic assumptions can naturally produce an interactive environment. The general framework introduced below has been used (e.g. Brock and Durlauf (1999a)) to interpret phenomena such as out-of-wedlock births and high school dropout rates, cases where individual decisions are likely to reflect the desire to conform to the behavior of a reference group.

Formally, consider a population of I individuals. Suppose that each individual chooses one of two actions, labelled -1 and 1. Suppose that each individual's utility is quadratic in his action and in the actions of others; what this means is that an individual experiences a payoff to his own choice which is influenced by the choice of each of the other agents in the population and that this effect depends on the square of the differences between the choices. Finally, we assume that each individual experiences a pair of stochastic shocks $\epsilon_i(1)$ and $\epsilon_i(-1)$ which influence the payoffs associated with the respective choices.

At the time of the choice, each individual is assumed to possess expectations E_i which apply to the choices of the others in the population. We will assume that these expectations are fixed at the time when agents make choices, so as to avoid any feedback from the stochastic components of the economy into beliefs. Hence, one can regard the model as one where agents form beliefs about others, experiences stochastic shocks which are only observable to themselves, and make decisions accordingly. As discussed above, this assumption will allow the joint probability measure to factor so that the relationship between the individual choice probabilities (which are conditional only on X_i's) and aggregate behavior is easy to analyze. The model generates interesting collective behavior because individuals are linked by the determinants of these expectations, which will depend on past realized behavior.

When the various elements of a decision problem of this type are additive, it turns out that, without loss of generality, (see Brock and Durlauf (1999a) for details) an individual's utility can be written (after normalization) as

$$V(\omega_i,X_i) = h(X_i)\omega_i - \frac{1}{2}E_i(\sum_{j \neq i} J(X_i,X_j)(\omega_i - \omega_j)^2) + \epsilon_i(\omega_i) \qquad (5)$$

This specification can be decomposed into an individual-specific component $h(X_i)\omega_i + \epsilon_i(\omega_i)$ and an interaction-based component $-\frac{1}{2}E_i(\sum_{j \neq i} J(X_i,X_j)(\omega_i - \omega_j)^2)$. We will refer to these two components as private and social utility respectively. Private utility can be further decomposed (without loss of generality) into its mean $h(X_i)\omega_i$ and a stochastic deviation $\epsilon_i(\omega_i)$. The terms $J(X_i,X_j)$ are measures of the strength of the disutility of nonconformity. This term can vary with the characteristics and identities of each of the agents. Most important, when the $J(X_i,X_j)$'s are all positive, there are collective incentives to conform which may lead to multiple equilibria and interesting dynamics.

In order to close the model, we place an assumption on the distribution of the random terms; this allows one to characterize the probabilities of different configurations of choices among the population of agents. We assume that the random terms are independent and extreme-value distributed which in turn means that the difference between $\epsilon_i(1)$ and $\epsilon_i(-1)$ is logistically distributed with parameter $\beta(X_i)$

$$Prob(\epsilon_i(-1) - \epsilon_i(1) \leq \gamma) \;=\; \frac{1}{1 + exp(-\beta(X_i)\gamma)}, \quad \beta(\cdot) \geq 0^3 \qquad (6)$$

Under this assumption, the model reduces to a particular instance of the standard binary choice framework when there are no interaction effects, i.e. $J(X_i,X_j) = 0 \;\forall\; i,j$. One advantage of this equivalence is that our theoretical model is written in a form that means it can be directly taken to data, for structural econometric estimation, as discussed in Brock and Durlauf (1999b).

From this distribution the individual choice probabilities can be

[3]This functional form is standard in the discrete choice literature. See Anderson, de Palma and Thisse (1992) for a justification.

computed.

$$Prob(\omega_i \mid X_1,...,X_I,Z) \sim$$
$$exp(h(X_i)\omega_i + E_i(\sum_{j \neq i} (\beta(X_i)J(X_i,X_j)\omega_i\omega_j))) \tag{7}$$

The conditional probability measures can be multiplied to construct the joint probability measure of the vector of choices $\underset{\sim}{\omega} = (\omega_1,...\omega_I)$. This joint measure is of the form

$$Prob(\underset{\sim}{\omega} \mid X_1,...,X_I,Z) \sim$$
$$exp(((\sum_i h(X_i)\omega_i + (\sum_i \sum_{j \neq i} E_i(\beta(X_i)J(X_i,X_j)\omega_i\omega_j))) \tag{8}$$

Once we have included a set of rules for expectation formation, the model is complete. Our model can be solved directly for several different specifications of the underlying parameters h, J, and β, which together characterize the private valuations, conformity effects and distribution of individual-specific randomness in the population.

The model we have described falls into a well-studied class of probabilistic systems. It is an example of a *random field.*[4] Random fields describe the joint distribution of large sets of random variables. In such systems, the probabilities describing one random variable conditional on the realizations of others are taken as given. The object of the study is to demonstrate the existence of joint probability measure consistent with these conditional probabilities and to characterize the resultant aggregate properties of the system. The joint probability measures are sometimes known as Gibbs measures due to their importance and historical origins in statistical mechanics.

iii. Global interactions

[4]Liggett (1985) and Durrett (1988) are standard references.

One class of models which falls into this framework has studied been in Brock and Durlauf (1999a). Suppose that all agents are homogeneous, so that there are no differences across individuals in the parameters used to characterized private utility; specifically assume each individual is characterized by a common h and β. Suppose too that each agent interacts with every other agent symmetrically, in the sense that

$$J(X_i, X_j) = \frac{J}{I-1} \;\; \forall\; j \neq i.^{5} \tag{10}$$

It is clear that under this specification, to the extent that agents wish to conform to the behavior of others, they wish to match the average behavior in the population, which we denote m. Hence we may take each individual as solving

$$max_{\omega_i} \;\; h\omega_i + \epsilon_i(\omega_i) + J\omega_i E_i(m) \tag{11}$$

Expressed this way, each choice is conditionally independent of the others, and so the set of decisions is an example of the mathematical structure described by eq. (1). Since all agents are identical, self-consistency of beliefs requires that

$$m = E_i(m) \tag{12}$$

which in this case means that the expected value of the choice level in the population is any m which solves

$$m = tanh(\beta h + \beta J m) \qquad (13)^{6}$$

[5]The normalization I in this expression makes the marginal substitution between private and social utility independent of population size.

Equation (13) is well known in the world of statistical physics as the mean field approximation of the Curie-Weiss model of magnetism. The following theorem characterizes the solutions to this equation.

Theorem: Multiple versus unique steady states

i. If $\beta J < 1$ and $h = 0$, $m = 0$ is the unique solution to (13).

ii. If $\beta J < 1$ and $h \neq 0$, there is a unique solution to (13) whose sign is the same as h.

iii. If $\beta J > 1$ and $h = 0$, there exist three solutions to (13): $m = 0$, and $\pm m^*(\beta J)$. Furthermore, $m^*(\beta J) > 0$ and $lim_{\beta J \Rightarrow \infty} m^*(\beta J) = 1$.

iv. If $h \neq 0$ and for fixed β and J there exists a threshold $H(h) > 0$ such that

a. if $\mid h \mid < H$, there exist three solutions to (13), one of which has the same sign as h, and the others possessing opposite sign.

b. for $\mid h \mid > H$, there exists a unique solution to (13) with the same sign as h.

This theorem illustrates both the nonlinearities and multiple steady states which are the hallmarks of interacting systems. Multiple equilibria exist in the sense that individual choices can, so long as βJ is large enough relative to βh, exhibit one of several distinct expected values each of which renders those choices individually rational. This occurs in two senses. First,

[6] $tanh(x) = (exp(x) - exp(-x))/(exp(x) + exp(-x))$. Brock and Durlauf (1999a) derives this equilibrium condition from first principles..

for a given βh, there will exist a threshold value such that if βJ exceeds this value, then there will exist three equilibria, otherwise, there will exist one equilibrium. Alternatively, for a given βJ greater than one, there will exist a threshold such that if βh is below it, there exist three equilibria, otherwise the equilibrium is unique. What this means is that aggregate behavior of the population is determined by a complicated interplay between the strength of the social interactions effect, measured by J, the strength of common private incentives to make one choice or another, h, and the degree of unobserved heterogeneity across individuals, as measured by the parameter β which indexes the likelihood of large absolute values of the difference in the stochastic components, i.e. $\epsilon_i(1) - \epsilon_i(-1)$.

The model is nonlinear with respect to the effect of a change in h on m. Hence, changes in private incentives will have very different effects on aggregate behavior depending on the level of the incentives and the strength of the social interaction effects. Indeed, the effect of a change in h will partially depend on whether it changes the number of equilibria, which will exceed one when the strength of the interactions effects are great enough.

What does such an abstract model say about a concrete social issue such as the rate of nonmarital fertility in poor communities? In our view, the model illustrates how peer-group effects and socially reinforced behavior produce nontrivial aggregate consequences and therefore speaks to such a problem. In particular, the model makes clear how the interplay of private incentives embodied in h and $\epsilon_i(\omega_i)$ interact with social influences embodied in J to create the possibility of widespread social pathologies which are collectively undesirable although produced by individually rational behavior.[7]

To give one example of how this framework provides policy-relevant insights, the model indicates how attempts (which we feel frequently occur in public policy discussions) to blame inner city social pathologies on either the culture of poverty or lack of economic opportunities are each incomplete. It is only when economic incentives associated with one or another type of behavior are weak (i.e. the magnitude of h is small) that strong social interactions (measured by J) can produce socially undesirable but individually rational behavior. In this sense, the model illustrates how common explanations of inner city pathologies are in fact complementary, despite the fact that they are usually portrayed as alternatives.

iv. Local interactions

A class of alternatives to the global interaction models is that of models with spatial structure. Agents have a location and are affected only by the behavior of their (suitably defined) neighbors. Schelling (1969, 1981) explored racial clustering of neighborhoods in a model of this type. Specifically, he analyzed the consequences for residential segregation when individual families possess a mild preference for neighbors like themselves. The consequence of individuals caring only about the identity of their immediate neighbors proved to be a global pattern of residential racial segregation. More recently, local interaction models have achieved some popularity in evolutionary game theory in the work of Blume (1993,1995), Ellison (1993), Binmore, Vaughn, and Samuelson (1995), among others. In addition, Glaeser, Sacerdote and Scheinkman (1996) have taken local interactions models to data and found evidence consistent with a role of social interactions in determining cross-community crime rates.

[7] For particular cases of deviations from neoclassical modelling assumptions, one can of course be much more precise in articulating the relationship between an economic environment and the likelihood or plausibility of certain deviations. For example, cognitive science has documented many circumstances in which human beings are most likely to deviate from strict definitions of rationality. See Piattelli-Palmarini (1994) for a delightful survey of these issues. So far as we know, there has been no work using interactions-based methods in which the modelling has been based on a detailed empirically motivated approach to loosening standard neoclassical assumptions on rationality. Rather, the work has typically used an ad hoc form of myopic belief formation.

Local interactions can be introduced into the baseline model by locating the agents on the vertices of a graph such that anyone pair of individuals are said to be neighbors if their respective vertices are connected by an edge. Formally, this has typically been done by setting $J(X_i, X_j) = 0$ if i and j are not neighbors, although alternative weighting schemes are certainly possible.

In the particular case of uniform local interactions, each individual is associated with a neighborhood n_i; $\#(n_i)$ denotes the neighborhood's population size. Each member of the neighborhood receives an equal conformity weight, so that $J_{i,j} = J/\#(n_i)$. A self-consistent equilibrium for this system is any set of solutions $m_1 \dots m_I$ to the set of I equations

$$m_i = tanh(\beta h \ + \frac{\beta J}{n_i} \sum_{j \in n_i} m_j) \tag{14}$$

This mapping must possess at least one fixed point and hence at least one self-consistent equilibrium exists.[8]

This system must exhibit at least one symmetric equilibrium, i.e., $m_i = m_j \ \forall \ i,j$, since at a common solution m the model reduces to the global interactions case. However, this framework allows for the possibility of multiple asymmetric equilibria as well; see Young (1999) for further discussion. While such cases can be technically complicated, they do point to the possibility of rich cross-group behavioral differences and thus provide a set of complementary approaches to capturing the phenomena which motivate Glaeser, Sacerdote, and Scheinkman (1996).[9] In a very different strand of work, Topa (1997) has used spatial correlation methods as a way of

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[8] These equations represent continuous mappings of elements of $[0,1]^I$ (the I dimensional unit cube) into itself, which means that Brouwer's Fixed Point Theorem applies.

[9] As formally discussed in Durlauf (1997), the local interactions model of Glaeser, Sacerdote, and Scheinkman (1996) is a special case of the general interactions model we have described.

uncovering interactions and finds spatial correlations in Chicago neighborhood unemployment rates that is consistent with an interactions-based model based on information flows.

v. Dynamics

Our discussion of multiple equilibria has thus far been static. In dynamic contexts, it is natural to ask whether and how a system of interactions of the type we described cycles between the steady state equilibria. Blume and Durlauf (1999) analyze this question, and show that over long horizons, the average population choice at a given point in time will tend to be close to the "best" (in an average welfare sense) equilibrium.[10] Intuitively, randomness means that a population will periodically switch across basins of attraction; the fact that one equilibrium produces higher average payoffs means that switches away from this equilibrium will be relatively less frequent than others. This result is compatible with a situation where the waiting times between switches are arbitrarily large for different equilibria. Hence, for population groups with different initial conditions, the multiple equilibria which emerge in the static case can represent arbitrarily persistent differences between groups over time. See Kandori, Mailath, and Rob (1993) for similar types of findings.

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[10] To be precise, when $h \neq 0$, any equilibrium with an expected average choice level with the same sign as h produces higher average utility than one that does not. This permits one to make social welfare statements about equilibria in our model. However, in general it will not be the case that one equilibrium Pareto dominating another, since it is always possible that the realized distribution of random utility terms is such (with likelihood approaching 1 as the number of agents goes to infinity) that some agents make choices with different signs at each possible equilibrium, which means someone is always made worse off in moving from one equilibrium to another.

3. How do interactions-based models contribute to the understanding of social science phenomena?

i. Substantive phenomena

By providing a framework for studying heterogeneous populations of agents, interactions-based models represent a natural environment for interpreting a number of interesting microeconomic specifications. Much of the exciting recent work in economic theory focuses on the aggregate implications of various deviations from the Arrow-Debreu model. Such deviations include incomplete markets, increasing returns to scale in production, and incomplete information. Further, substantial attention has now been given to studying the implications of different rationality assumptions. In our view, microeconomic assumptions such as imperfect communication between agents, which leads to market incompleteness, or lack of *a priori* knowledge of the structure of the aggregate economy, which leads to nontrivial learning, make most sense in the context of complex, heterogeneous environments. Put differently, an assumption such as rational expectations seems relatively natural in a representative or homogeneous agent environment. Heterogeneity of beliefs becomes relatively compelling as a behavioral assumption when the set of markets and agents becomes large.

To be sure, topics ranging from monopoly behavior to learning have been productive and should continue to be explored in environments simpler than those which are best studied using interactions. Where interactions-based models seem uniquely useful is in the study of phenomena which are most naturally embedded in large heterogeneous populations.

ii. Interactions-based models as a language for research

Interactions-based methods are also useful because they make the analysis of particular questions simpler would be the case using alternative approaches. In this regard, we distinguish between methods which are uniquely able to permit certain types of analysis and methods which make the analysis relatively simpler to achieve. Socioeconomic systems admit many different levels and types of description (as do natural systems, of course). Different types of description, whether in terms of conditional probabilities characterizing agents, or an explicit extensive form game formulation of strategies, etc., may act to facilitate analysis. Hence, it is possible that the choice of a particular modelling structure has practical implications for the ability of researchers to make progress. Theoretical work has made clear that the mathematical structures by which one describes an interacting system are extremely conducive to the identification and analysis of emergent patterns in heterogeneous environments. While such patterns may otherwise be deducible using alternative descriptions, the exercise may be much more tedious and demanding. Hence, even if the insights obtainable from interactions models can be obtained through other modelling approaches, the interactions-based approach is still useful.[11]

More generally, we reject the idea that there exists a unique set of "natural kinds" through which one accurately represents a socioeconomic system. Rather, particular phenomena may be better understood using one language versus another even when these languages are perfectly translatable from one to another. By analogy, the typical Hilbert space can be generated from more than one basis, each of which can be used to analyze all properties of the space. Nevertheless, in particular contexts, one basis may facilitate analysis relative to others. For example, the complex exponentials are a particularly useful basis for the Hilbert space of L^2 functions; this fact is of course the basis for the importance of Fourier analysis in applied (as opposed to theoretical) mathematics. Similarly, a computer language can be

[11]See Little (1991) pg. 188 for an example of how a similar pragmatic argument can be made in defense of methodological individualism.

relatively good for a particular programming need, even though the same need can be met can be met with an alternative.

To see how this language argument works, observe that in a standard neoclassical general equilibrium environment, it is possible to describe each individual's behavior as a function of the decisions of other agents, so long as this functions reflect market clearing conditions. However, it is far from clear how this would facilitate analysis. For example, such a redescription would, we believe, have made it far more difficult to establish the First Welfare Theorem, whose standard proof is based on budget sets and does not, in fact really rely on market clearing, at least in terms of the actual structure of the proof; rather the proof works with prices. Price variables which be substituted out if one were to write the model exclusively in terms of interactions.

Our argument on the value of interactions-based models as a language for conducting research is related to the one made in McIntyre (1996) that the identification of laws in the social sciences is a function of the type of description employed. We differ from McIntyre in that while he argues that the existence of laws may be description-specific, we argue that, as a practical matter, the ability of scientists to identify laws concerning the relationship may be description-specific.[12]

4. Interactions-based modelling and general equilibrium theory

General equilibrium theory is well equipped, under standard sets of assumptions concerning the completeness of markets, convexity of technology and preferences, etc., to characterize a number of features of economies with heterogeneous populations. These features include the existence and uniqueness of sets of equilibrium prices as well as welfare theorems concerning the optimality of the resulting allocations. However, the

[12]See Anderson (1972) for related discussion.

Sonnenschein-Mantel-Debreu theorem (Sonnenschein (1973), Mantel (1974), Debreu (1974)) indicates that under a set of the standard assumptions under which general equilibrium theory has been developed, there exist essentially no restrictions on the behavior of data aggregates, either within a cross-section or intertemporally. By implication, there are essentially no restrictions placed by the theory on aggregated data.[13] This absence of empirical restrictions on aggregate data in no way challenges the importance of general equilibrium theory as an overarching organizing framework for economics. Rather, the absence of aggregate empirical restrictions in general equilibrium theory suggests that the theory, at least as classically conceived, is incomplete as a way of understanding economic phenomena.

This incompleteness is evident when one tries to account for the presence of common types of aggregate behavior which emerge across different economic environments. A list of such common aggregate behaviors (and associated interactions-based explanations would include: 1) Zipf's law, which states that within a country, the natural logarithm of a city's population is proportional to its population ranking (Krugman (1990)), 2) large cross-community differences in socioeconomic outcomes despite similar microeconomic characteristics (Glaeser, Sacerdote, and Scheinkman (1993), Brock and Durlauf (1999a)), 3) stratification of communities by income and ethnicity, (Bénabou (1993,1996), Durlauf (1996a,b)) and 4) spatial agglomeration of economic activity (Arthur (1987)).

What makes these aggregate features interesting is their presence in many different contexts despite the presence of substantial heterogeneity across or within the groupings in which they occur. This heterogeneity

[13] It is worth noting that the Debreu-Mantel-Sonnenschein theorem has not been extended to infinite horizon economies, where equilibrium existence proofs typically employ more restrictive assumptions than other cases. Also, Boldrin and Montruccio (1986) have found a similar result which says that a representative agent model can be constructed which replicates any set of aggregate time series on investment and consumption.

suggests that a number of features of economic behavior exist whose aggregate properties are robust with respect to at least some features of the microeconomic specifications of individual actors. In other words, a number of phenomena such as racial segregation, the ratios of population among the largest cities of a country, and substantial persistence in business cycles, characterize a range of very different socioeconomic environments. Interactions-based systems embody the mathematics of such robust properties, and in this regard commend themselves as tools in economic modelling.

Of course, recognizing that general equilibrium theory (as opposed to particular general equilibrium models) fails to generate aggregate data restrictions, any of the common features which one might identify are perfectly compatible with the theory. The relevant point is that this compatibility does not mean that general equilibrium theory provides an understanding of these features.[14]

To see why compatibility is not equivalent to understanding, consider the relation between the neo-Darwinian synthesis and speciation. Modern evolutionary theory provides a framework in which to study patterns of speciation. However, without a successful theory of developmental biology to explain how genetic information expresses itself in phenotypes, evolutionary theory is not capable of explaining why some speciation patterns emerge and not others. By analogy, we are interested in asking how the application of interactions modelling to economics can provide a deeper understanding of common aggregate features beyond the formal compatibility of these features

[14]The meaning of "understanding" in the context of scientific theories is controversial among philosophers of science; see Little (1991) for a discussion. For our purposes, we say that a theory provides understanding of a phenomenon when it provides a causal explanation of how and why the phenomenon occurs in a way which permits a researcher to extrapolate to related contexts. We proceed on the basis that the argument in favor of theories which produce understanding is robust to whatever ambiguities exist at the borders of the concept.

with general equilibrium theory.

The interactions approach can contribute to the development of such an understanding by identifying how certain aggregate behaviors emerge from particular classes of individual characteristics and particular specifications of how individuals interact. One does not, however, get something for nothing by employing this approach in order to generate aggregate dynamics. Particular emergent phenomena depend upon particular sets of individual-level specifications; these methods can only be valuable to the extent that these individual specifications are plausible descriptions of actual economic environments. In the absence of any restrictions on the distribution of individual characteristics, the Sonnenschein-Mantel-Debreu theorem implies that general equilibrium theory imposes only extremely limited restrictions on aggregate data. What interactions methods bring is the possibility that common types of aggregate behavior emerge for widely varying collections of individual characteristics.

The strategy of identifying classes of individual interactions which produce common data implications is paralleled by some recent work on aggregation in economics. Grandmont (1989), Caplin and Leahy (1991), Hildebrand (1994), and Caballero and Engel (1995) have studied economic environments in which restrictions on the distribution of initial conditions and/or individual characteristics allow inferences about aggregate behavior. However, they have not emphasized the collective and emergent features of aggregate behavior which are the hallmark of the interactions approach.

Finally, we would note that for many of the aggregate phenomena in which we are interested, externalities or other types of market failures typically exist. Such features do not, in general, fall under the purview of general equilibrium theory. (General equilibrium theory with incomplete markets, see Magill and Quinzii (1996) is an important exception to this.) In this sense, interactions-based models again complement general equilibrium theory, this time by characterizing alternative microeconomic foundations.

5. Interactions-based models and reductionism in economics

The application of interactions-based analysis to economics illustrates a context in which economic analysis is and ought to be nonreductionist. We argue this in two senses.

First, in many economic environments, there does not exist a unique mapping between specific microeconomic characteristics to aggregate properties, at least when these characteristics are restricted to individual preferences and technologies. As discussed in Blume (1997), this indeterminacy can be attributed to the absence of an explicit characterization of the interaction structure between individual actors. The mathematics of interactions provide tools which can resolve the problem of multiple equilibria (in the sense of explaining how a particular equilibrium is selected) which is necessary to bridge microeconomic structures and macroeconomic outcomes.

Second, the linkage between classes of interaction structures and aggregate outcomes is necessary if the goal of economic modelling is to understand aggregate behavior. While knowledge of the characteristics of each economic agent can, in principle, allow one to characterize a particular aggregate environment, in such environments this knowledge does not provide much insight as to why the environment emerges. As Anderson (1972) puts it, such environments are not "constructivist" in that it is impossible to reason from the properties of the individual objects by themselves to the property of aggregates. It is the nature of collective interactions that is critical in understanding aggregate economic behavior.

Here, some standard examples taken from science are helpful. The statement that a group of water molecules have formed into ice is not reducible in an explanatory sense to information about each water molecule in isolation. Similarly, knowledge of the DNA structure of all species would not lead to an understanding of the collective properties of the biosphere, a point emphasized by Lewontin, Rose, and Kamin (1985). The property of ice or biosphere diversity is emergent in the sense that it occurs at a more aggregated level of measurement than the level at which the individual elements of the system are described. Crutchfield (1994) defines an emergent property in essentially this way.[15]

To see how this applies to economics, again consider our model of binary choice with social interactions under the assumptions of global interactions and rational expectations. When $\beta J > 1$ and $h = 0$, all individuals are identically specified and each has an ex ante 50% chance of using either 1 or -1, yet their behavior is compatible with two average choice levels with nonzero mean. This asymmetric outcome from a symmetric underlying structure, referred to in physics as broken symmetry, is a canonical example of an emergent phenomenon (Anderson and Stein (1984)).

Notice that this example is not consistent with Crutchfield's definition, since each agent in the global case reacts to the expected average choice, while the realization of the average choice is the object under analysis. However, similar properties hold for the local interactions case. For example, if $h = 0$, and agents are arrayed on a two-dimensional lattice, then there exists a critical J_c such that if $J > J_c$, the model exhibits multiple average choice levels in the large economy limit, whereas if $J < J_c$ then the average will always converge to zero in the limit.

In our view, socioeconomic phenomena such as patterns of out-of-wedlock births, racial residential segregation, and technology diffusion, have a

[15]It can be a far from a simple matter to determine whether a system exhibits emergence. In one prominent case, philosophers and cognitive scientists are actively debating whether consciousness is an emergent property of the brain; see Searle (1993) and Churchland (1986) for expositions of opposing sides in this debate.

similar interpretation. This claim is at least partially justified by the success of theoretical models of these phenomena in demonstrating how they can emerge from the combination of well-specified individual decision rules and relatively simple interaction structures. In short, while we accept the central role of microfoundations in macroeconomics as articulated by the modern Chicago school of macroeconomics, we also believe that macroeconomics is a distinct discipline from microeconomics (and by implication neoclassical general equilibrium theory) due to the presence of these emergent properties. This argument in favor of a nonreductive explanation of socioeconomic phenomena appeared earlier when we discussed the relationship between interactions models and general equilibrium theory.

While we emphasize the nonreductionist aspect of interacting economic models, one should recognize that neoclassical economic analysis often focuses on emergent properties.[16] Perhaps the clearest case is the First Welfare Theorem of Economics, which states that (under a well specified set of conditions) every competitive equilibrium is Pareto efficient, i.e. that it is impossible to make anyone better off without making someone else worse off. This aggregate-level efficiency is an emergent property of a system in which individual agents are pursuing their own ends. Other types of emergent properties abound within the context of specific economic environments. Becker (1962) provides a set of cases in which aggregate implications of neoclassical economics survive as emergent properties in environments which deviate from neoclassical assumptions. Thus, we regard our emphasis on the nonreductionist aspects of interactions-driven economic environments to be consistent with the spirit of much existing analysis.

At the same time, interactions-based models are fully consistent with methodological individualism, which we define as the requirement that the

[16]General invisible hand arguments of the type discussed by Nozick (1974) pp. 18-22 implicitly rely on the existence of particular (and conjectured) emergent properties of social systems.

individual agents within an economic system follow well-defined decision rules and that the analysis of the system proceed from the specification of these rules. This requirement simply means that any higher order properties of the system emerge either directly or indirectly from the rules which determine the behavior of individuals. These higher order properties would occur, for example, if one were to find scaling laws in residential segregation patterns, in which the scaling laws exist with reference to communities, whose compositions are endogenously determined by individual decisions.

While the general ideas of methodological individualism are fully compatible with interactions, this approach is important in extending methodological individualism to richer environments than those which are conventionally studied in economics. As discussed in Blume (1997) a powerful critique of the particular instantiation of methodological individualism found in most modern economic theory may be based on the failure of many theories to account for the relationships between individual decisionmaking and different levels of aggregation of the environment in which they interact. This failure lies at the heart of some of the most severe criticism made by social scientists who are not economists as well as by some heterodox economists; Granovetter (1985) summarizes this position well:

"Classical and neoclassical economics operates, in contrast, with an atomized and *under*socialized conception of human action...The theoretical arguments disallow by hypothesis any impact of social structure and social relations on production, distribution, or consumption." (pg. 55)

It is precisely this ability to provide socially mediated connections between individual behavior and larger socioeconomic aggregates that makes the interactions approach useful in breaking what we regard as obviously artificial disciplinary barriers between economics and sociology when studying complicated problems such as social pathologies.

6. New applications of interactions-based modelling

As should be clear from this discussion, there is nothing about conventional economic problems which makes interactions-based modelling especially appropriate. Indeed our view is that there are a wide range of range of social and political phenomena where interactions-based approaches can be fruitful.

i. Language

Sociolinguistic studies have made clear that there exists a deep relationship between socioeconomic status and language use. For example, it is well documented that the use of nonstandard grammar or pronunciation by a given individual is more probable when someone is poor and male, controlling for other factors – see Chambers (1995) chapter 2 and Wardhaugh (1995) chapter 7 for surveys of evidence on this. What the sociolinguistics and psychology literatures makes clear is that language is closely tied to individual identity and that both are in turn influenced by one's reference groups; see Akerlof and Kranton (1999) for a provocative discussion of how identity shapes socioeconomic outcomes; their discussion places sociolinguistics findings in a broad context. Further, there is some recognition that dialectic choice, defined in terms of adherence of standard grammar or pronunciation, can have important economic consequences. For example, Jupp, Roberts, Cook-Gumperz (1982) and Akinasou and Ajirotutu (1982) argue that ethnic minorities are at a relative disadvantage in job interviews due to differences in language structure and style.

While sociolinguistic studies seem to have made clear that linguistic behavior is determined by one's economic and social status, there has been, little formal modelling of the processes by which language and socioeconomic communities jointly evolve across time.[17] This would appear to be an ideal case for understanding the interplay of private and social incentives. The use of Black English, for example, is a choice which is conditioned both by social interactions (the language choices of one's social network) as well as the incentives set by the economy as a whole.[18] In turn, use of Black English influences socioeconomic opportunities. Formal modelling using interactions could both make rigorous many standard ideas in sociolinguistic theory as well as provide a nice test case for the assessment of statistical tools designed to uncover interactions.

Beyond the issue of dialect choice, one can also imagine using interactions-based models to study regional patterns in pronunciation.[19] Labov (1996) is a recent example of empirical work on this issue, documenting the evolution and persistence (despite homogenizing factors such as mass media) of such differences. These spatial patterns would intuitively seem to be a prime candidate for a social interactions explanation, since it hard to imagine any purely private incentives for such choices. Put differently, since pronunciation does nothing more than facilitate communication with others, the choices of others are naturally the object that determines these choices; pronunciation choices may even be thought of as examples of network externalities of the type that apply to choice of computer operating systems.

[17]Among economists, a notable exception is Lazear (1995). Lang (1986) discusses the effects of language barriers on wages. Akerlof (1997) discusses the importance of understanding the interdependence of language and economic status.

[18]Notice that this type of choice need not be conscious. What we mean is that the choice-based framework we employ can be used to understand how individuals take up behaviors, such as belief in God, tendency towards liberal versus conservative political views, etc. in which the private and social incentives are not employed in a conscious calculus, but rather simply represent factors which influence individual outcomes.

[19]We thank William Brock for this suggestion.

ii. Security issues

Interactions models have had little application in security issues.[20] However, it is clear that many of the ideas and metaphors which motivate socioeconomic contexts are also relevant in this case. One possible question is the probability of a nuclear weapons accident. As made clear in Sagan (1993), understanding the probability of an accidental launch requires understanding the behavioral outcomes of an organization (military of course) comprised of many decentralized, yet highly interdependent decisionmakers. Indeed, a major argument in defense of so-called "normal accidents" theory (so dubbed by Sagan), at least as developed by Perrow (1984), is that there exist sufficiently many nonlinear interactions between elements of large organizations that mistakes will invariably arise which cannot be accommodated by safety features which can only accommodate foreseeable contingencies. Rochlin (1997) has further argued that the extremely high degree of computerization of defense capabilities has produced an extremely high degree of interdependence within various defense organizations, so this general concern about organizations seems especially applicable to defense.

Could interactions-based methods help clarify the probability of a nuclear weapons-related accident? It is certainly plausible to believe that the answer is yes. Formal modelling of command and control systems could be achieved with a great deal of accurate detail about microstructures. We are willing to conjecture two features of such an exercise. First, it will be possible to produce scenarios under which accidents occur at unacceptably high frequencies. One message of interactions-based studies of stock price

[20]This is not to say that security and defense issues have not been subject to formal modelling – see Epstein (1997) for a nice introduction to successful examples of the applications of mathematics to issues in this area.

movements generated by interdependent traders (Arthur, Holland, LeBaron, Palmer, and Tayler (1997)) or the distribution of rates of social pathologies (Glaeser, Sacerdote and Scheinkman (1995)) is that extreme outcomes in the sense of highly correlated behavior in a population have a nontrivial probability of occurring due to positive feedback effects; hence a similar result in the context of nuclear accidents seems reasonable. Second, it may nevertheless be possible to design redundancies and safety mechanisms within the system to render this probability negligible. Why? Because the same interdependence which may make accidents seem relatively likely can also mean that small but common influences on individual decisions can have large aggregate effects. By making each actor in the system slightly more cautious, the feedback effects may render the system as a whole much more cautious. How this can be done naturally requires expertise in the details of the organization of interest (and indicates why interactions models complement rather than substitute for institutional knowledge), but the capacity for large heterogeneous systems to experience collective order due to positive interactions suggests that this goal can in principle be accomplished.

One might argue that normal accidents theories are based on the claims that certain contingencies cannot be foreseen rather than on claims about the complexity of organizations per se. However, if the concern about interactive environments is that there are contingencies whose nature we cannot characterize, let alone whose probabilities we cannot evaluate, then it is incoherent to talk about the probability of accidents being high or low. Also, the issue for system performance is not the identifiability of the range of possible shocks to the system, but rather the identification of the range of responses and interconnections. If the argument that complex interdependent organizations are likely to produce errors is to make sense, it is presumably a statement about how the interactions in such systems evolve, which is why interactions-based modelling seems a natural approach.

7. Conclusions

Interactions-based models provides a powerful set of structures that are conducive to modelling a wide range of socioeconomic environments. These models are capable of incorporating individual heterogeneity and cross-individual dependencies which have proven difficult to model in the past and are able to do so in ways with interesting empirical implications, in particular with respect to aggregate patterns.

Although we are confident that interactions-based analysis has much to offer economics, we recognize that our views are still fairly speculative. While this approach has provided numerous theoretical insights, there has yet to be a decisive empirical demonstration either of the interactions which underlie the microstructure of the approach or of the presence of the sorts of emergent phenomena which are the hallmark of aggregate implications of these theories. Even Zipf's Law, which is often taken as the most evident scaling law in economics, has yet (at least in our opinion) to be subjected to sufficiently rigorous econometric examination. Further, as made clear in Manski (1993,1997) and Brock and Durlauf (1999b), the econometric identification of interaction effects is complicated, with identifiability depending sensitively on details of the modelling context.

At this same time, it should be recognized that there have been a number of interesting developments on the empirics of interactions. One problem in the empirical analysis of interactions is that one is interested in inferences about these effects for heterogeneous populations in just the same way as one wishes to theorize in the presence of heterogeneity. Such populations are, for cases such as neighborhoods and schools, endogenously sorted into relevant groups. Manski (1995) provides many insights into how one can obtain bounds on various effects in the presence of self-selection and heterogeneity; Brock and Durlauf (1999b) show how to adapt these ideas to identify interactions effects. Additionally, Brock and Durlauf (1999b) provide conditions under which self-selection, if properly modelled, can facilitate identification. Both these approaches seem very promising, although much remains to be done. Beyond the development of new econometric methods, it will likely be necessary to construct new data sets in order to accurately characterize the microstructure of particular types of interactions. See Rauch (1996) for an interesting exercise along these lines.

Despite these interesting developments, the long run success of the interactions-based approach in economics depends on a clear demonstration of its empirical salience over a range of contexts. This of course will require that more empiricists and econometricians participate in the analysis in order to complement the economic theorists whose work launched the field. The interactions between these groups should themselves prove to be two-sided. Just as empirical research is needed to characterize the nature of interactions in actual socioeconomic phenomena, which should then inform the ways theories are constructed, theoretical research can help to identify new ways of thinking about data.

Bibliography

Akerlof, G., (1997), "Social Distance and Social Decisions," Econometrica, 65, 1005-1027.

Akerlof, G. and J. Yellin, (1994), "Gang Behavior, Law Enforcement and Community Values," in Values and Public Policy, H. Aaron, T. Mann and T. Taylor eds., Washington DC: Brookings Institution Press.

Akerlof, G. and R. Kranton, (1999), "Economics and Identity," mimeo, University of Maryland and forthcoming, Quarterly Journal of Economics.

Akinasou, F. N. and C. S. Ajirotutu, (1982), "Performance and Ethnic Style in Job Interviews," in Language and Social Identity, J. Gumperz, ed., Cambridge: Cambridge University Press.

Anderson, P., (1972), "More is Different," Science, 177, 393-396.

Anderson, P. and D. Stein, (1984), "Broken Symmetry, Emergent Properties, Dissipative Structures, Life: Are They All Related," in Basic Notions of Condensed Matter Physics, P. Anderson, ed., Menlo Park: Addison Wesley.

Anderson, S., A. de Palma, and J.-F. Thisse, (1992), Discrete Choice Theory of Product Differentiation, Cambridge: MIT Press.

Arthur, W. B., (1987), "Urban Systems and Historical Path Dependence," in Urban Systems and Infrastructure, R. Herman and J. Ausubel, eds., Washington D.C.: National Academy of Sciences/National Academy of Engineering.

Arthur, W. B., (1989), "Increasing Returns, Competing Technologies and Lock-In by Historical Small Events: The Dynamics of Allocation Under Increasing Returns to Scale," Economic Journal, 99, 116-131.

Arthur, W. B., B. LeBaron, R. Palmer, and P. Tayler, (1997), "Asset Pricing Under Endogenous Expectations in an Artificial Stock Market," in The Economy as a Complex Evolving System II, W. B. Arthur, S. Durlauf and D. Lane, eds. Menlo Park: Addison-Wesley.

Bak, P., K. Chen, J. Scheinkman, and M. Woodford, (1993), "Aggregate Fluctuations from Independent Sectoral Shocks: Self-Organized Criticality in a Model of Production and Inventory Dynamics," Ricerche Economiche, 47, 3-30.

Becker, G., (1962), "Irrational Behavior and Economic Theory," Journal of Political Economy, 70, 1-13.

Bell, A., (1995), "Dynamically Interdependent Preferences in a General Equilibrium Environment," mimeo, Department of Economics, Vanderbilt University.

Bénabou, R., (1993), "Workings of a City: Location, Education, and Production," Quarterly Journal of Economics, CVIII, 619-652, 1993.

Bénabou, R., (1996), "Equity and Efficiency in Human Capital Investment: The Local Connection," Review of Economic Studies, 62, 237-264.

Binmore, K., L. Samuelson, and R. Vaughn, (1995), "Musical Chairs: Modeling Noisy Evolution," Games and Economic Behavior, 11, 1-35.

Blume, L., S. Salant, and D. Holt, (1989), "Coping with Rejection: The Empirical Analysis of Experimental Data," working paper, University of Michigan.

Blume, L., (1993), "The Statistical Mechanics of Strategic Interaction," Games and Economic Behavior, 5, 387-424.

Blume, L., (1994), "An Evolutionary Analysis of Keynesian Coordination Failure," mimeo, Cornell University.

Blume, L, (1995), "The Statistical Mechanics of Best-Response Strategy Revision," Games and Economic Behavior, 11, 111-145.

Blume, L., (1997), "Population Games," in The Economy as a Complex Evolving System II, W. B. Arthur, S. Durlauf and D. Lane, eds. Menlo Park: Addison-Wesley.

Blume, L. and S. Durlauf (1999), "Equilibrium Concepts for Models with Social Interactions," mimeo in progress, Cornell University.

Boldrin, M. and L. Montruccio, (1986), "On the Indeterminacy of Capital Accumulation Paths," Journal of Economic Theory, 40, 26-39.

Brock, W., (1993), "Pathways to Randomness in the Economy: Emergent Nonlinearity and Chaos in Economics and Finance," Estudios Economicos, 8, 1, 3-55 and Social Systems Research Institute Reprint #410, Department of Economics, University of Wisconsin at Madison.

Brock, W., (1997), "Asset Price Behavior in Complex Environments," in The Economy as a Complex Evolving System II, W. B. Arthur, S. Durlauf and D. Lane, eds. Menlo Park: Addison-Wesley.

Brock, W. and S. Durlauf, (1997a), "Discrete Choice with Social Interactions" mimeo, University of Wisconsin at Madison and forthcoming, Review of Economic Studies.

Brock, W. and S. Durlauf, (1999b) "Interactions-Based Models," mimeo, University of Wisconsin at Madison and forthcoming, Handbook of Econometrics, vol. V, J. Heckman and E. Leamer eds., North-Holland, forthcoming.

Brock, W., and C. Hommes, (1997), "Rational Routes to Randomness," Econometrica, 65, 1097-1128.

Caballero, R. and E. Engel, (1995), "Microeconomic Adjustment Hazards and Aggregate Dynamics," Quarterly Journal of Economics, CVIII, 683-708.

Caplin, A. and J. Leahy, (1991), "State-Dependent Pricing and the Dynamics of Money and Output," Quarterly Journal of Economics, CVI, 683-708.

Chambers, J. K., (1995), Sociolinguistic Theory, Oxford: Blackwell Publishers.

Churchland, P. S., (1986), Neurophilosophy, Cambridge: MIT Press.

Clark, K. B., (1982), Dark Ghetto, Wesleyan: Wesleyan University Press.

Coleman, James, (1990), Foundations of Social Theory, Cambridge: Harvard University Press.

Crutchfield, J., (1994), "Is Anything Ever New? Considering Emergence," in Cowan, G., D. Pines, and D. Meltzer, eds., (1994), Complexity: Metaphors, Models, and Reality, Menlo Park: Addison Wesley.

Debreu G., (1974), "Excess Demand Functions," Journal of Mathematical Economics, 1, 15-21.

Deutsch, D., (1997), The Fabric of Reality, London: Allen Lane.

Durlauf, S., (1993), "Nonergodic Economic Growth," Review of Economic Studies, 60, 349-366.

Durlauf, S., (1996a), "A Theory of Persistent Income Inequality," Journal of Economic Growth, 1, 75-93.

Durlauf, S., (1996b), "Neighborhood Feedbacks, Endogenous Stratification, and Income Inequality," in Dynamic Disequilibrium Modelling: Proceedings of the Ninth International Symposium on Economic Theory and Econometrics, W. Barnett, G. Gandolfo, and C. Hillinger, eds., Cambridge University Press.

Durlauf, S., (1997a), "Limits to Science or Limits to Epistemology?," Complexity, 2, 3, 31-37, 1997.

Durlauf, S., (1997b), "Statistical Mechanics Approaches to Socioeconomic Behavior," in The Economy as a Complex Evolving System II, W. B. Arthur, S. Durlauf and D. Lane, eds. Menlo Park: Addison-Wesley.

Durrett, R., (1988), Lecture Notes on Particle Systems and Percolation, Belmont: Wadsworth and Brooks/Cole.

Ellison, G., (1993), "Learning, Local Interaction, and Coordination," Econometrica, 61, 1047-1072.

Epstein, J., (1997), Nonlinear Dynamics, Mathematical Biology, and Social Science, Menlo Park: Addison-Wesley.

Föllmer, H., (1974), "Random Economies with Many Interacting Agents," Journal of Mathematical Economics, 1, 51-62.

Glaeser, E., B. Sacerdote and J. Scheinkman, (1996), "Crime and Social Interactions," Quarterly Journal of Economics, CXI, 507-548.

Glaeser, E. and J. Scheinkman, (1998), "Estimating Social Interactions," mimeo.

Georgii, H.-O., (1988), Gibbs Measures and Phase Transitions, New York: deGruyter.

Grandmont, J.-M., (1989), "Transformation of the Commodity Space, Behavioral Heterogeneity, and the Aggregation Problem," Journal of Economic Theory, 57, 1-35.

Granovetter, M., (1985), "Economic Action and Social Structure: The Problem of Embeddedness," American Journal of Sociology, 91, 481-510.

Hildebrand, W., (1994), Market Demand: Theory and Evidence, Princeton:

Princeton University Press.

Ioannides, Y., (1990), "Trading Uncertainty and Market Structure," International Economic Review, 31, 619-638.

Jupp, T., C. Roberts, and J. Cook-Gumperz, (1982), "Language and Disadvantage: The Hidden Process," in Language and Social Identity, J. Gumperz, ed., Cambridge: Cambridge University Press.

Kandori, M., G. Mailath, and R. Rob, (1993), "Learning, Mutation, and Long Run Equilibrium in Games," 61, 29-56.

Kelly, M., (1997), "The Dynamics of Smithian Growth," Quarterly Journal of Economics, CXII, 939-964.

Kirman, A., (1983), "Communication in Markets: A Suggested Approach," Economic Letters, 12, 1-5.

Kirman, A., (1992), "Whom or What Does the Representative Individual Represent," Journal of Economic Perspectives, 6, 2, 117-136.

Kollman, K., J. Miller, and S. Page, (1992), "Adaptive Parties in Spatial Elections," American Political Science Review, 86, 929-937.

Krugman, P., (1996), The Self-Organizing Economy, Oxford: Basil Blackwell.

Labov, W., (1994), Principles of Linguistic Change, Volume 1: Internal Factors, Oxford: Blackwell Publishers.

Labov, W., (1996), "The Organization of Dialect Diversity in North America," mimeo, Department of Linguistics, University of Pennsylvania.

Lang, K., (1986), "A Language Theory of Discrimination," Quarterly Journal of Economics, 405, 363-382.

Lazear, E., (1995), "Culture and Language," NBER Working Paper no. 5249.

Lewontin, R., L. Kamin and S. Rose, (1985), Not in Our Genes: Biology, Ideology, and Human Nature, New York: Pantheon Books.

Liggett, T., (1985), Interacting Particle Systems, New York: Springer-Verlag.

Little, D., (1991), Varieties of Social Explanation, Boulder: Westview Press.

McIntyre, L., (1996), Laws and Explanations in the Social Sciences, Boulder: Westview Press.

Manski, C., (1993), "Identification of Endogenous Social Effects: The Reflection Problem," Review of Economic Studies, 60, 531-542.

Manski, C., (1997), "Identification of Anonymous Endogenous Social Interactions," in The Economy as an Evolving Complex System II, W. B. Arthur, S. Durlauf and D. Lane, eds., Menlo Park: Addison-Wesley.

Manski, C., (1995), Identification Problems in the Social Sciences, Cambridge: Harvard University Press.

Mantel, R., (1974), "On the Characterization of Excess Demand," Journal of Economic Theory, 7, 348-353.

Maruta, T., (1996), "Binary Games with State Dependent Stochastic Choice," working paper, MEDS.

Monderer, D. and L. Shapley, (1996), "Potential Games," Games and Economic Behavior, 14, 124-143.

Morris, S., (1996), "Contagion," mimeo, University of Pennsylvania.

Nozick, R., (1974), Anarchy, State, and Utopia, New York: Basic Books.

Perrow, C., (1984), Normal Accidents: Living with High Risk Technologies, New York: Basic Books.

Piattelli-Palmarini, M., (1994), Inevitable Illusions, New York: John Wiley.

Rauch, J., (1996), "Trade and Networks: An Application to Retail Entrepreneurship," mimeo, UC San Diego.

Rochin, G., (1997), Trapped In the Net: The Unanticipated Consequences of Computerization, Princeton: Princeton University Press.

Sagan, S., (1993), The Limits of Safety, Princeton: Princeton University Press.

Schelling, T., (1971), "Dynamic Models of Segregation," Journal of Mathematical Sociology, 1, 143-186.

Searle, J., (1993), The Rediscovery of the Mind, Cambridge: MIT Press.

Sonnenschein, H., (1973), "Do Walras' Identity and Continuity Characterize the Class of Community Excess Demand Functions?," Journal of Economic Theory, 6, 345-54.

Topa, G., (1997), "Social Interactions, Local Spillovers and Unemployment," mimeo, New York University.

Wardhaugh, R., (1995), An Introduction to Sociolinguistics, Oxford: Blackwell Publishers.

Young, H. P., (1993), "The Evolution of Conventions," Econometrica, 61, 57-84.

Young, H. P., (1998), Individual Strategy and Social Structure, Princeton: Princeton University Press.

Young, H. P., (1999), "Diffusion in Social Networks," mimeo, Johns Hopkins University and Brookings Institution.