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INTRODUCTION

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This issue contributes to the discussion of the relation between individual and aggregate behavior. The basic feature of all the models presented is that they allow for direct interaction between the individuals. This, it is shown, leads to a number of interesting phenomena that are difficult to account for in standard models. The basic message is that the inclusion of heterogeneous interacting agents allows us to escape from the pitfalls associated with the reduction to a representative individual and furthermore to show that aggregates will, in general, have behavior that is different from that of the component individuals. Lastly, complex aggregate behavior is not necessarily the result of complicated individual reasoning, it can emerge from very simple rule following by individuals.

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The purpose of this special issue is to reexamine the relationship between individual and aggregate economic behavior. The papers here consider a number of basic questions. Are aggregate outcomes influenced by the fact that individuals interact directly with each other? Does the way in which this interaction is organised matter? What is the impact on aggregate behavior of the fact that individuals learn about their environment and about the behavior of the economy? Does the resultant modification of expectations of the individuals have an effect on the dynamics of aggregate outcomes? What is the effect of the heterogeneity of individual characteristics? None of these questions is original but, nevertheless, the papers presented here suggest that taking them together should lead us to reconsider the nature of standard models of aggregate behavior.

A first reaction, and one which is backed by a long tradition in macroeconomics, would be to argue that if it is aggregate behavior that interests us, we need be concerned only with looking at the relationship among aggregate variables and not worry about the possibly complicated interrelated micro-behavior that generates those relationships. Although any economist knows that individual economic agents constantly interact with each other in different ways and for different purposes, it could be argued that to analyse this is unnecessary for the explanation

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of macroeconomic phenomena. Yet the briefest scrutiny of statements by policy-oriented economists and policy makers themselves suggests that they, unlike some theoretical macroeconomists, do attribute considerable importance to the way in which individuals interact with each other economically. Take one example. Such terms as "contagion," "panic," "confidence," and "interdependence" are frequently found in explanations of the financial crisis in the Far East. These expressions are used to describe changes in market expectations or the way in which changes in the situations of some major actors affect others. This implies the existence of some sort of structure of interaction through which agents and markets are affected or become "infected." The view that is shared by the papers in this special issue is that it is, at least in part, this interaction between individuals and the networks through which it is organized that mediates the passage from micro to macro-behavior and that we cannot afford to ignore this. Indeed, it is striking that whereas we have developed a better understanding of the importance of the contractual relations that exist between various individuals and bodies in the economy, little heed of this is taken in macroeconomic analysis. This is like trying to develop our knowledge of how the organs of the body function while continuing to treat the body as a whole as a collection of homogeneous cells. We know that the way in which economic activity is regulated, the way in which contractual arrangement are made, the methods used to dispose of assets and the groups or location within which individuals function all have an impact on economic outcomes. It seems unreasonable to assume that all of these effects can be subsumed under some parameter in an aggregate production or demand function.

This discussion of the role of interaction among individuals, cells, or particles is very much present in other disciplines. Statistical physics has much to say about the aggregate behavior of systems of interacting particles, for example. However, the situation in economics is complicated by the fact that the practice of analysing macro-relationships, without considering their micro-foundations, is now, in economics, almost universally considered as "unscientific." Indeed, and here one has to be careful about what one means by "explain," economists are not alone in claiming that macro-phenomena should be explained by an analysis of the underlying micro-behavior of a system.

The message contained in the papers in this issue is that we should indeed be interested in the relationship between micro and macro-behavior. Yet, this cannot be understood without taking into account the way in which individuals' decisions and actions are influenced by those of other agents. Theoretical microeconomists have typically been preoccupied since Walras and Pareto with, for example, the existence and efficiency of the competitive equilibrium state of a fully specified economy. However, until relatively recently they were much less concerned with the problem of how individual actions were coordinated and how this influences aggregate outcomes.

The individuals in a modern economy interact with each other in many different ways, they communicate, they imitate, they inform and are informed, and they act strategically with each other. They do so through a mass of different networks

and these in turn are interlinked. Some of the interaction between agents takes place through formal structures such as markets others through direct or indirect communication via social or other links. Like a biological organism, the closer one looks at the structure of an economy, the more complicated its organization appears. Yet, consideration of direct interaction between individuals and of the organisational features of economies is strangely absent from most economic models, in particular macroeconomic models.

Each of the papers here considers specific aspects of this interaction and tries to explain phenomena that seem to elude the traditional models with "representative agents," rational expectations and no direct interaction between economic actors.

One of the pillars of modern macroeconomic models is the "rational expectations" equilibrium. Now this can be considered as simply an equilibrium condition, if agents have those expectations then they will be correct, or, more ambitiously, one can argue that the economy or market will learn its way toward such a situation [Evans and Honkopohja (2001)].

In the first paper, Hommes et al. look at the problem of learning and expectations formation in a simple model The problem is, as I have mentioned, a very pervasive one. Either one argues that rational expectations are to be taken as an equilibrium reference point or, more problematically, one can ask by which process of expectations formation did the economy get there? What the authors do is to conduct experiments to see how close the subjects' behavior is to that, which would be predicted by the theory. The agents have no knowledge of the structure of the model but they simply learn from knowledge of the past realizations of prices and past predictions. The latter is important because there is at least an indication for the subjects that there is a feedback from expectations to prices. When their model is configured so that the Rational Expectations equilibrium is stable, the subjects come close to achieving that state. In a theoretically unstable configuration, the mean price is not far from the steady state Rational Expectations Equilibrium, but there are large fluctuations around it. This is precisely the excess volatility phenomenon, which has been so widely discussed in the literature. Here again the fact that the subjects are interacting with each other and that there are important feedback effects causes the dynamics to be very different than one might expect from simple individual level theory.

The paper by Di Martino et al. uses the methods of statistical physics to examine the aggregate behavior of an economic system. They argue that the methods of mathematical economics have in the past aimed at general results—such as existence, uniqueness, and efficiency—which hold for broad classes of economic environments. Yet, as they point out, analyzing the typical macroeconomic behavior beyond these general results is very difficult, especially when agents are heterogeneous and interact with each other. However, the authors observe that one does not necessarily have to study the microeconomic behavior in detail understand the complex macro-behavior of a system. Indeed, many laws that govern macro-behavior are of a statistical nature. The statistical properties of random systems have been a central research issue in statistical mechanics for the past

two decades, and extremely powerful analytical tools to calculate them have been developed. The authors propose a simple model with linear random technologies and look at the competitive equilibria as the number of commodities and techniques increases. They show how there are two regimes for the equilibria, which are sharply separated, and which of the regimes is attained depends crucially on the relation between the number of commodities and the number of technologies. Their model leads them to suggest that in a dynamic framework the economy will evolve toward the critical ratio and will tend to be on the frontier between the two regimes. Thus, the introduction of stochastic interaction provides a very different picture of macroeconomic outcomes than do more conventional models.

Delli Gatti et al.'s contribution also tries to expand on the restrictive framework generally employed in macroeconomics. They relax the assumption of the representative agent or more specifically of homogeneous agents. Their model has as its conceptual core the interaction of heterogeneous firms and the banking system.

Even in standard macroeconomic models, it is sometimes recognized that heterogeneity is a necessary ingredient of important business cycle features (such as composition effects). However, as the authors point out, the nature and consequences of heterogeneity are not thoroughly explored. There is always a point in the analysis, often for technical reasons, at which the representative agent is resuscitated and heterogeneity is simply put on one side. The theoretical reasons for resorting to the representative agent are well understood. This framework is still the cornerstone of standard macroeconomics [Stoker (1993)], although its drawbacks are widely recognized [Kirman (1993)]. One justification for its use is that heterogeneity is short-lived. But there is no reason to believe that the distribution of heterogeneous agents, which affects the dynamics of the macro variables, will collapse to a degenerate one. Macroeconomic models, which rely on the representative agent, therefore, oversimplify the analysis of business fluctuations and of the transmission mechanism of monetary policy. In a financial accelerator model along the lines of that proposed by Greenwald and Stiglitz (1993), the authors explore the consequences of heterogeneity of firms' size and degree of financial fragility. The analytical intractability of even such a simple framework, leads the authors to simulate an agent-based model.

They find that the financial fragility of heterogeneous firms and the banking system and their interaction on the credit market play a crucial role in shaping the evolution over time of output, the capital stock and net worth. Their simulations reproduce a whole array of stylized facts: the distribution of firms' size is right-skewed and described by a power law that shifts and rotates over the business cycle, cumulative changes of output during business cycles follow a Weibull distribution, the rates of change of aggregate and firms' output follow a similar Laplace distribution; the distribution of the age of exiting firms is exponentially distributed, and so on. They propose, in conclusion, a number of extensions that would make their model more realistic but would, they claim, still reproduce the stylised facts. Thus, the incorporation of heterogeneity allows one to examine phenomena that are not even envisaged in the standard model and to give a more plausible account of business cycles.

Another more specific area where standard analysis does not seem to be capable of reproducing certain stylized facts is that of financial markets. In models of these markets, "the efficient markets hypothesis" is pervasive and this conveys the idea that the price of an asset should reflect underlying "fundamentals." Furthermore, the link between fundamentals and prices is such that all information available, both public and private, about fundamentals should be incorporated into prices. If this is the case, then the only reason for prices to change must be the arrival of completely new information that was not predictable. If it had been, it would have been forecast. Hence, asset prices must appear to fluctuate randomly and whether this is so has been the subject of extensive debate. The essential feature of such an approach is that behavior can be analyzed in terms of one "representative" individual's behavior. An important aspect of this view is that asset values or exchange rates reflect what is expected to happen to fundamentals. Because expectations cannot be observed, it is clearly not possible to falsify the efficient market hypothesis directly. The problem with this approach that allows one to characterize the equilibrium path of asset prices, is that its predictions are frequently very different than observed empirical facts. Perhaps the most striking puzzle is the volatility of asset prices as compared to that of the underlying fundamentals raised already by Shiller (1981). Despite numerous efforts by economists to explain it, the "excess volatility" puzzle remains. Why should it be the case that in the case of stocks, for example, prices are so much more volatile than the associated dividend streams? Once again, it can be argued that the relationship between fundamentals over time is highly "nonlinear" and that small changes in today's values may lead to large changes in the future, thus significantly changing current asset prices.

It is difficult, however, to believe that there could be a sudden change in the fundamentals that would lead agents to simultaneously agree within half a day that returns in the future had gone down by over 20%. Yet this is what would have to be argued for the October 1987 episode on the New York Stock Exchange. A more convincing explanation is that there was some sort of herding behavior that led to the abrupt change. An example of the sort of behavior that can produce this sort of phenomenon is given by Scheinkman and Xiong (2003) and an excellent review is provided by Chamley (2004).

In their paper, Yang and Satchell examine the consequence of such herding behavior for an important feature of financial markets, the cross-correlations in security returns. As they observe, imitation is one of the most common features of human behavior, in general, and economic behavior, in particular. It can lead to systematically erroneous decision making and convergence of behavior across individuals, and it is this that is often referred to as herding. They show both analytically and numerically that herding, which can be thought of as a short-lived and unstable coordination on the same investment behavior, can endogenously induce asset-dependency. In addition, they show that there exists a self-reinforcing process, whereby market extreme events amplify the herd effect and this further exacerbates asset dependency.

They examine the Taiwan and U.K. equity markets, and find that when they simulate their model with herding the results are closer to the real patterns of

asset-dependency than those obtained from a static model with isolated, noninteracting individuals. They make an important observation about the desirability of transparent financial regulation. Because such regulation is likely to increase herding as it makes individual actions easier to observe, it may lead to consequences that are far from those desired by the regulators. In addition, they give statistical evidence of asymmetric correlation patterns in the top fifty stocks in both the U.K. and Taiwan equity markets. This suggests that portfolio diversification as a means of managing portfolio risk is unlikely to be effective in periods of extreme losses, when herding is likely to be important, in these markets.

Alfarano and Lux study a simple model of a financial market that has heterogeneous agents and reproduces some of the stylized facts (unit-roots, fat-tails, and volatility clustering) of the price series for those markets. A number of agent-based models have already achieved this and have shown that such features emerge from the interactions of agents. Yet, these models are often too complex to be analytically tractable. They show that even a very simple model of a financial market with heterogeneous interacting agents is capable of reproducing what they refer to as "these ubiquitous statistical properties." Their framework is sufficiently simple to allow them to obtain some analytical results using concepts from statistical mechanics. In their model, traders may hold one of two views: fundamentalists and chartists [Frankel and Froot (1988)], The way in which they interact is based on a variant of the herding mechanism introduced by Kirman (1993). They do some simulations of their model and the statistical analysis of simulated data points indicates long-term dependence in the auto-correlations of squared and absolute returns and hyperbolic decay in the tail of the distribution of raw returns, both with estimated decay parameters in the same range as those of empirical data. A direct interpretation of this as power law behavior would be misleading, however, as theoretical analysis, excludes the possibility of "true" scaling behavior. This is because of the Markovian nature of the underlying process and the boundedness of returns. The model, therefore, as they point out, only mimics power law behavior. In much the same way as do the phenomenological volatility models analyzed in LeBaron (2001), the usual statistical tests are not able to distinguish between true or pseudo-scaling laws in the dynamics of their artificial market.

Kirman et al. also analyze the role of direct interaction between agents in financial markets. They relax one of the standard assumptions of models of speculative markets for foreign exchange and allow for two interacting markets. Their perspective remains that of a situation in which, within each market, agents of different types interact. However, not only do agents change their type as a result of their interaction with others but also there are two countries each inhabited by currency traders who influence each other through the exchange rate. In their model, both foreign and domestic traders buy the assets of both countries. As in many models of this type, the speculators in both countries have different possible rules for forecasting the exchange rate. Here they are limited to the classical—"chartist" and "fundamentalist"—choice and their demand for the assets of each country is determined by their forecasts. Extra heterogeneity is introduced because

the perceptions of the fundamentals in each country are not necessarily the same. They use a simple reinforcement rule to determine the probability with which the individuals will use a rule. This probability depends on the success an agent had with the different rules in the past. Once again, the role of learning is emphasized. The interaction of the demands of the fundamentalist and chartist agents in the two countries determines the market-clearing rate at each point in time. Then the question is, how does the temporary equilibrium evolve over time? What they show is that the interaction between the traders produces features of the series of equilibrium exchange rates that correspond to some of the stylized facts for these markets. They show that there are periods in which the exchange rates track the fundamentals of one of the countries and others in which "bubbles" appear. However, these bubbles inevitably burst. Because there are traders of both nationalities there is no need, as in other models, to provide any exogenous shock, in terms, for example, of an exogenous supply of foreign exchange. This work has been reinforced by theoretical results obtained by Foellmer et al. (2005), in which it is shown that the stochastic price process in a similar model will exhibit the same features.

In sum, it is clear that the sort of models presented in the papers in this issue provide a rich framework within which to analyze the relation between aggregate phenomena and individual behavior. The fact that individuals interact directly with each other allows us to think of economies or markets as having aggregate behavior, which does not simply reflect some average of individual agents but is closer to behavior of the complex interactive systems studied in other disciplines.

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