Economic Dynamics

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Economic dynamics is concerned with fluctuations in the economy. Most economic variables, such as gross domestic product (GDP), production, unemployment, interest rates, exchange rates and stock prices, exhibit perpetual fluctuations over time. These fluctuations are characterized by sustained growth of production and employment as well as large oscillations in relative changes or growth rates. The fluctuations vary from fairly regular business cycles in macroeconomic variables to very irregular fluctuations for example in stock prices and exchange rates, in financial markets. In this note we discuss some approaches to the theory of economic fluctuations, emphasizing the role of non-linear dynamic models.

In contrast to many dynamic phenomena in natural sciences, uncertainty always plays a role in an economy, at least to some extent. Therefore a purely deterministic model seems inappropriate to describe fluctuations in the economy, and a stochastic dynamic model is needed. Nevertheless, a key question in economic dynamics is whether a simple, nonlinear dynamic model can explain a *significant part* of observed economic fluctuations.

Brief History

There are two contrasting viewpoints concerning the explanation of observed economic fluctuations. According to the first (New Classical) viewpoint, the main source of fluctuations is to be found in exogenous, random shocks (news about economic fundamentals) to an inherently stable, often linear economic system. Without any external shocks to economic fundamentals (preferences, endowments, technology, etc.), the economy would be stable and converge to the unique steady state (growth) path. According to the second, opposing (Keynesian) viewpoint, economic fluctuations are not caused by chance or random impulses, but should be explained by nonlinear economic laws of motion. Even without any external shocks to the fundamentals of the economy, fluctuations in prices or other economic variables may arise. It is an old Keynesian theme that fluctuations are not determined by economic fundamentals only, but are also driven by volatile, self-fulfilling expectations ('animal spirits', market psychology).

The view that business cycles are driven by external random shocks was propagated in the 1930s for example by Ragnar Frisch and Jan Tinbergen (sharing the first Nobel Prize in Economic Sciences in 1969 "for having developed and applied dynamic models for the analysis of economic processes"). They observed that simple, linear systems buffeted with noise can mimic time series similar to those observed in real business cycle data. To several economists this approach was unsatisfactory however, because it does not provide an *economic* explanation of business cycles, but rather attributes them to external, random events. In the 1940s and 1950s Nicholas Kaldor, John Hicks and Richard Goodwin, developed nonlinear dynamic models with locally unstable steady states and stable limit cycles as an explanation for business cycles. These early nonlinear business cycle models however suffered from a number of serious shortcomings. First of all, the laws of motion were too 'ad hoc', and in particular they were *not* derived from rational behavior, that is, from utility and profit maximizing principles. Secondly, the simulated time series from the models were too regular compared to observed business cycles, even when small dynamic noise was added to the models. Finally, expectation rules were 'ad hoc' and along the regular cycles, agents made 'systematic' forecasting errors.

The Role of Expectations

The most important difference between economics and natural sciences is perhaps the fact that an economic system is an *expectations feedback* system. Decisions of economic agents are based upon their expectations and beliefs about the future state of the economy. Through these decisions expectations feed back into the economy and affect actual realization of economic variables. These realizations lead to new expectations, in turn affecting new realizations, implying an infinite sequence of expectational feedback. For example, in the stock market optimistic expectations that stock prices will rise, will lead to a larger demand for stocks, which will cause stock prices to rise. This process may lead to a self fulfilling speculative bubble in the stock market. A theory of expectation formation is therefore a crucial part of economics, in particular for modeling dynamic asset markets.

In the early business cycle models, simple, ad hoc expectations rules were employed, such as naive expectations (where the forecast of the economic variable is simply the latest observation of that variable) or adaptive expectations (where the forecast is a weighted average of the previous forecast and the latest observation). An important problem with simple forecasting rules is that typically agents make systematic forecasting errors, especially when there are regular cycles. A smart agent would learn from her mistakes and adapt her expectations rule accordingly. Another problem is that if an agent is to use a simple forecasting rule, it is far from clear which simple rule to choose in a particular model. With the development of empirical, econometric analysis of business cycles it became clear that unrestricted models of expectations preclude a systematic inquiry into business fluctuations. These considerations led to the development of *rational expectations*, a solution to the expectations feedback system proposed by John Muth (1961) and applied to macroeconomics for example by Robert Lucas and Thomas Sargent. Rational expectations means that agents use all available information, including economic theory, to form optimal forecasts and that, on average, expectations coincide with realizations. In a deterministic model, without noise and randomness, rational expectations implies perfect foresight (no mistakes at all); in a stochastic model, rational expectations coincides with the conditional mathematical expectations given all available information (no mistakes on average, no systematic bias).

In the 1970s and 1980s, the rational expectations critique culminated in the development of New Classical economics and real business cycle models, based upon rational expectations, intertemporal utility and profit maximization and perfectly competitive markets. This approach outdated the early Keynesian nonlinear business cycle models of the fifties. Due to the discovery of deterministic chaos and other developments in nonlinear dynamics however, the last two decades have witnessed a strong revival of interest in nonlinear endogenous business cycle models.

Nonlinear Dynamics

In mathematics and physics things changed dramatically in the 1970s due to the discovery of deterministic chaos, the phenomenon that simple, deterministic laws of motion can generate unpredictable time series. This discovery shattered the Laplacian deterministic view of perfect predictability, and made scientists realize that long run prediction may be fundamentally impossible, even when laws of motion are known exactly. Inspired by 'chaos theory', economists (for example Richard Day and Jean-Michel Grandmont) started looking for nonlinear, deterministic models generating erratic time series similar to the patterns observed in real business cycles. This search led to new, simple non-linear business cycle models within the paradigm of rational expectations, optimizing behavior and perfectly competitive markets, generating chaotic business fluctuations.

In the 1980s, several economists (for example William Brock, Davis Dechert, Jose Scheinkman and Blake LeBaron) also employed nonlinear methods, such as correlation dimension tests, from the natural sciences to look for evidence of nonlinearity and low deterministic chaos in economic and financial data. This turned out to be a difficult task, because the methods employed require very long time series and the methods are very sensitive to noise. One can say that evidence for low dimensional deterministic chaos in economic and financial data is weak (but it seems fair to add that, because of the sensitivity to noise, the hypothesis of chaos buffeted with dynamic noise has not been rejected), but evidence for nonlinearity is strong. In particular, Brock, Dechert and Scheinkman have developed a general test (the BDS-test) based upon ideas from U-statistics theory and correlation integrals, to test for nonlinearity in a given time series; see Brock et al. (1996) and Brock, Hsieh and LeBaron (1991) for the basic theory, references, applications and extensions. The BDS test has become widely used, in economics but also in physics, and has high power against many nonlinear alternatives.

Bounded Rationality

Already in the 1950s, Herbert Simon pointed out that rationality requires unrealistically strong assumptions about the computing abilities of agents and proposed that *bounded rationality*, with limited computing capabilites and agents using habitual rules of thumb instead of perfectly optimal decision rules, would be a more accurate description of human behavior. Nevertheless, as noted above, rational expectations became the dominating paradigm in dynamic economics in the seventies and eighties. Nonlinear dynamics, the possibility of chaos and its implications for limited predictability shed important new light on the expectations hypothesis however. In a simple (linear) stable economy with a unique steady state path, it seems natural that agents can learn to have rational expectations, at least in the long run. A representative, perfectly rational agent model nicely fits into a linear view of a globally stable and predictable economy. But how could agents have rational expectations or perfect foresight in a complex, nonlinear world, with prices and quantities moving irregularly on a strange attractor and sensitivity to initial conditions? A boundedly rational world view with agents using simple forecasting strategies, perhaps not perfect but at least approximately right, seems more appropriate for a complex nonlinear world. These developments contributed to a rapidly growing interest in bounded rationality in the 1990s (see for example the survey in Sargent (1993)). A boundedly rational agent forms expectations based upon observable quantities and adapts her forecasting rule as additional observations become available. Adaptive learning may converge to a rational expectations equilibrium or it may converge to an "approximate rational expectations equilibrium", where there is at least some degree of consistency between expectations and realizations (see for example Evans and Honkapohja (2001) for an extensive and modern treatment of adaptive learning in macroeconomics).

Interacting Agents and Evolutionary Models

The representative agent model has played a key role in economics for a long time. An important motivation for the dominance of the rational agent model dates back to the 1950s, to Milton Friedman who argued that non-rational agents will be driven out of the market by rational agents, who will trade against them and simply earn higher profits. In recent years however, this view has been challenged and heterogeneous agent models are becoming increasingly popular, especially in financial market modeling (see for example Kirman (1992) for a critique on representative agent modeling).

Many heterogeneous agent models are artificial, computer simulated markets. This work views the economy as a complex evolving system composed of many different, boundedly rational, interacting traders, with strategies, expectations and realizations co-evolving over time (see for example, work at the Santa Fe Institute collected in Anderson et al. (1988)). Two typical traders types arising in many heterogeneous agent financial market models are fundamentalists and chartist or technical traders. Fundamentalists base their investment decisions upon market fundamentals such as dividends, earnings, interest rates or growth indicators. In contrast, technical traders pay no attention to economic fundamentals but look for regular patterns in past prices and base their investment decision upon simple trend following trading rules. An evolutionary competition between these different trader types, where traders tend to follow strategies that have performed well in the recent past, may lead to irregular switching between the different strategies and result in complicated, irregular asset price fluctuations. It has been shown, for example by Brock and Hommes (1997, 1998), that in these evolutionary systems, rational agents and/or fundamental traders do not necessarily drive out all other trader types, but that the market may be characterized by perpetual evolutionary switching between competing trading strategies. Non-rational traders may survive evolutionary competition in the market (see for example, Hommes (2001) for a survey and many relevant references). Lux and Marchesi (1999) show that these type of interacting agent models are able to generate many of the stylized facts, such as unpredictable returns, clustered volatility, fat tails and long memory, observed in real financial markets.

Future Perspective

A good feature of the rationality hypothesis is that it puts natural discipline on agents' forecasting rules and minimizes the number of free parameters in dynamic economic models. In contrast, the 'wilderness of bounded rationality' leaves too many degrees of freedom in modeling, and it is far from clear which out of a large class of habitual rules of thumb is most reasonable. Stated differently in a popular phrase: 'there is only one way (or perhaps a few ways) one can be right, but there are many ways one can be wrong'. The philosophy underlying the evolutionary approach is to use simple forecasting rules based upon their performance in the recent past. In this type of modeling, 'evolution decides who is right'. Bounded rationality, heterogeneity, adaptive learning and evolutionary competition all create natural nonlinearities. Nonlinearity is therefore likely to play an increasingly important role in the future of economic dynamics.

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