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Cars H. Hommes

# The economy as a complex nonlinear system

**Cars H. Hommes** is Professor in Economic Dynamics at the University of Amsterdam and Director of CeNDEF (The Center for Nonlinear Dynamics in Economics and Finance), a multi-disciplinary research group that started in October 1998 by a Pionier grant from the NWO. His current research interests include nonlinear economic dynamics; bounded rationality; and expectation formation and learning.

**You are the director of the CeNDEF group. How would you describe the research of that group?**

The CeNDEF group has a clear research philosophy. Our main focus is on dynamic models with boundedly rational heterogeneous agents. In these models, a key role is played by nonlinear dynamics, which has been my main interest since the start of my career. My PhD thesis, in fact, was on applications of nonlinear dynamics in economics.

Heterogeneity is a very natural source of nonlinearity, which is why we have done a lot of work on heterogeneous agent models. If you have different agents that change strategies over time, then the switching between strategies will lead to a highly nonlinear dynamic system – even if the strategies themselves are linear.

In the real world people are heterogeneous; they do different things and change their strategies over time. They learn and adapt their behaviour, switch between strategies – and that creates nonlinearities, which is why I think studying nonlinear systems is important for economics.

**Did your endeavours lead to interesting results on how “the economy really works” that you could not get with traditional models?**

Agent-based modelling in finance has a large literature on models with two

different types of traders: fundamentalist traders and technical traders. The switching between these two types of individual strategies and heterogeneous expectations seems to play an important role in determining aggregate market outcomes. My work with William Brock (University of Wisconsin) started on that. In 1997 we published a paper in *Econometrica* on heterogeneous expectations, and in 1998 we wrote another paper that applied this evolutionary switching framework to financial markets. Those models have been calibrated and estimated on financial data, and have also been tested in laboratory experiments at CeNDEF during the last ten years. The results of those experiments can be described quite well by our theoretical switching models.

**Instability in economic systems gets a lot of attention in your work. Does that focus allow you to say something about the economy that traditional models cannot address?**

Yes. Take the model with fundamentalists and trend followers. This model has been fitted on S&P 500 stock market index data to see whether switching between these strategies is significant. One of my former PhD students, Sebastiano Manzan, estimated the parameters of this model using 130 yearly data points of the S&P 500, and he found that over time the fraction of fundamentalists and trend

followers changes. There are periods when you have a lot of trend followers – the late 90s, for example, when we had the Internet (or dot-com) bubble.

When you have a bubble, it almost always starts with a fundamental change in the market. In the late 90s, this change was driven by the invention of the Internet, a fantastic technology that was expected to create profit opportunities. However, in a model in which agents learn to switch to trend-following behaviour because that strategy has performed well in the last few years, the trend is reinforced – causing a much stronger bubble than would otherwise occur.

What comes out of our research is that trend-following behaviour can be very important, especially when you have positive feedback loops. Say the price of a stock rises. Trend followers will then predict further price rises, which means that they will buy at the current price, causing the price to rise. Trend followers will make profits, as they correctly predicted the price rise. In that case, more agents switch to trend following – so that the price becomes even higher, leading even more agents to switch to optimistic strategies, etc., thereby creating a bubble. I believe this is an important insight for regulatory policy and also for monetary policy, because in macroeconomics one often finds positive feedback.



**Could you give a concrete example of a situation in which heterogeneous agent-based models and traditional models give very different predictions?**

That's a difficult question, because policy based on agent-based modelling is in its infancy. But take the question: "how can we prevent a future financial crisis?" We have written a paper on the perils of financial innovation in a boundedly rational world. The common wisdom in finance is that financial innovation, such as the development of new derivative products, is a good thing because it stabilizes the economy and increases welfare. There are theorems that prove this, but these typically hold only under the (unrealistic) assumption of rational expectations. We studied financial innovation in a heterogeneous expectations model, and found out that if agents are boundedly rational – in the sense that they switch between fundamentalist and trend-following strategies based upon their recent performance – then financial innovation is a "bad" thing: it destabilizes the economy and decreases average welfare.

There is a simple intuition for this result. When there are more financial products, agents take bigger positions because they think they can hedge away the risks. At the start of a trend, trend followers take bigger positions so that their profits will be bigger. In a model with reinforcement learning in which agents switch to strategies that are performing well, these higher profits increase the share of trend followers – which further destabilizes the system. In the end, this bursts the bubble and decreases average welfare. So here you have a very simple example where the policy implications are completely different in models with rational- and boundedly rational agents.

Of course, in reality it is very difficult to find out whether the stabilizing or the destabilizing effect dominates, because it is also clear that financial instruments have welfare-improving properties due to better spreading of risk. I think it is important to not only think about these issues in highly stylized models, but also to try and build a realistic agent-based model that includes all of the complicated financial instruments we see in real markets – and to see what happens in agent-based simulations.

“In the **real world** people are heterogeneous; they do different things and change their strategies over time. They learn and adapt their behaviour, switch between strategies – and that creates nonlinearities.”

**Do you think these insights will help to improve policies in the future? Will policymakers listen?**

Yes, I believe so. To illustrate the interest: the NWO (Dutch Organization for Scientific Research) has a programme on complexity for which they have set aside 7 million euros, distributed over 14 projects. CeNDEF was lucky to get one of these complexity grants in cooperation with the DNB (Dutch Central Bank). The DNB is very interested in complex systems because they think complex systems can help to explain the financial crisis, and may even help to prevent future crises. So practitioners and policymakers are definitely interested.

A few months ago I was at the FED in Washington at a conference on learning in macro- and monetary models, and I was invited to give a lecture on complex systems and heterogeneous expectations. There were quite a few mainstream people in the audience, and there was a panel discussion on policy models. A lot of FED and IMF models are based on rational agent theory, and people at this conference were emphasizing the importance of including non-rational behaviour in their models.

In practice, only rational agent models are used to make predictions. Now, suppose that the assumption of rationality is wrong. This would mean that the policymaker has a big problem. If I were a policymaker, I would certainly not bet all my money on one type of model. I would let the policy recommendations be made by different types of models, and see whether you get important differences or not – and then use that as an input for the policy decisions.

Laboratory experiments show us that individual and aggregate behaviour is not at all like rational behaviour, or what rational expectations models would predict. As a policymaker I would be worried about that. You can say “these experiments are highly stylized and very simple, not like the real world”. But if rational expectations does not work in these simple environments, why would it work in very complicated environments like those modelled by the IMF?

**If heterogeneous expectations, bounded rationality and nonlinearities are so important, why have these factors been ignored for so long in mainstream macro models?**

I’m not sure that I’m the right person to answer that question; you should really ask some of my colleagues. Personally, I can think of several reasons. It’s a matter of tradition, but also of training. If you do not learn about it in your Bachelor or Masters programme, you simply will not know about it. I was brought up in nonlinear dynamics, studying mathematics in Groningen. If you studied mathematics or physics you would automatically come across nonlinear dynamics in seminars or courses – but in economics that is still not the case. But it is changing. Here at the University of Amsterdam, in both the econometrics Masters programme and the TI programme you can take some courses in nonlinear dynamics and bounded rationality.

**It’s on offer, but not obligatory. You can avoid it easily, and many people who do macroeconomic modelling never look beyond the mainstream.**

In any MPhil programme, a lot of the “indoctrination” happens in the first year. So when there is a lot of mainstream modelling in the first year with very good and enthusiastic lecturers, then for students it is entirely natural to take field courses in that area and write a thesis with an advisor they already know from the first year. I think that’s one of the reasons that relatively few students take courses in nonlinear dynamics or bounded rationality. Another reason is that nonlinear global dynamics is difficult; it’s easier to work with a linear approximation.

A good thing about the TI programme is that for each research group there’s a lecture once a year that introduces the research group to first-year TI students. I have done it a couple of times, and have observed that, for most students, nonlinear dynamics is like magic. When you think about dynamic processes, it is natural to think about convergence to a constant steady state. For some, it may also be natural to think of oscillations and periodical motion. The possibility of irregular, chaotic fluctuations, however, is beyond their imagination – and no wonder, because the discovery of chaos has been viewed as one of the scientific revolutions of the 20th century.

**So, it be fair to say then that you are not entirely happy with the TI programme?**

**Would you like to see a nonlinear dynamics course in the first year?**

Well I don’t like to complain, but in my view there is too much mainstream economics in the first year. I think it should be more heterogeneous. On a couple of occasions I have suggested to the directors that they might want to add some nonlinear dynamics in the first year. There is a course on dynamic optimization – but why not spend two weeks on methods of nonlinear dynamics, together with computer simulations? Or, even better: replace one of the five (!) (mainstream) micro- or macro courses by a basic course on complex systems in economics. It is important that students are confronted with complexity and nonlinear dynamics at an early stage – in order to show them that not everything converges to a steady state. Unfortunately, my efforts to convince the people at TI of that view have not yet been successful.

**Would you go so far as to say that nonlinear dynamics doesn’t penetrate the mainstream because PhD programmes, by and large, ignore this area – or would you also cite other reasons?**

Academia is extremely conservative. Even the current financial and economic crisis will not lead to big changes, I think, and rational models will continue to dominate in the top-five journals.

I was lucky that my first paper with William Brock got published in *Econometrica* – and that has been part of the reason why our work on heterogeneous expectations has been quite influential. At that time I was rather young, and thought it would be possible to convince mainstream economists of the importance of this type of work. But, regrettably, things did not change that much. Even nowadays, I hear too often the same negative comments from (mainstream) referees that I heard already 15 years ago.

**What kind of comments?**

For example, that nonlinear dynamics is not important, because a linear approximation is sufficient. Or that bounded rationality models are too ad hoc, that there are too many degrees of freedom. Or, that more realistic, agent-based, models are not analytically tractable – and that the results depend on simulations. There is scepticism about what you can learn from simulations. Too

many economists still prefer a more abstract model for which you can find analytical results – even though the assumptions of these abstract models are also very abstract, and might not be very realistic.

#### So, what can we learn from these simulations?

When you carry out simulations, you have to proceed carefully and systematically. I think that the work we do here at CeNDEF manages to find a good equilibrium between simple stylized models, which are still partly tractable, and agent-based simulations. For instance, one can often still do a local stability analysis of steady states and compute the first bifurcation (i.e. the onset of instability). This information gives you some economic intuition about the model, which can be supplemented by systematic simulations. From these simulations, for example, you can get statistics that could provide information about the regularities of the model.

#### What about the other critique, on the ad hoc assumptions about the agents?

The critique that a model is ad hoc is an easy critique that is too often used to reject papers. With every model there is an issue of how realistic the assumptions are and how ad hoc they are. In agent-based modelling, a lot of people calibrate their model on real data. They compare the outcomes of their model with statistical regularities, the stylized facts, of real data. That is also what we do here at CeNDEF. We also run experiments and compare the assumptions in our model to the observed behaviour in the lab. These things bring discipline to our models. So we justify our assumptions. Is a realistic simulation model not worth more than an abstract analytically tractable model with unrealistic assumptions? In my view, (at least) 10-20% of the articles published in the mainstream journals should be agent-based bounded rationality models. Of course, the authors should have a reasonable story behind their model, and validate their assumptions by empirical data and/or experiments. But I am optimistic that, wherever economics is going in the short run, in the end it will become a behavioural science once again. ●



inDepth

By Darrell Duffie

# Post-reform competition in the derivatives markets

**The Dodd-Frank Act, which is aimed primarily at improving financial stability, might also lead to significantly more competition in the over-the-counter derivatives market. Much depends on regulatory interpretations of the Act and on rulemaking outside the US, particularly in London.**