University of Amsterdam

Amsterdam School of Economics

CeNDEF@15

15TH ANNIVERSARY OF CeNDEF

“new ideas provide tools and techniques to better describe and predict the real economy”

CeNDEF

After losing in 1720 a substantial part of his fortune in the South Sea Bubble, Sir Isaac Newton, at that time Master of the Mint, remarked that he could calculate the motions of stars, but not the madness of people. This of course is what many mainstream economists try to do. They try to describe human madness in mathematical representations, applying all sorts of reductionistic modelling techniques to gain a better understanding of human behaviour. However the proverbial invisible hand often turns out to have a bad case of Parkinson's, as economic outcomes are quite different from what the models predict. On top, the recent credit crunch and the subsequent near-death experience of the global financial markets, its effects on the real economy and therefore the life of each and everyone of us illustrate the cascading failures of the models. They not only failed to predict the crash but may even have helped cause it.

During the last fifteen years the CeNDEF group of the Amsterdam School of Economics has worked very hard on a set of new ideas to provide tools and techniques to better describe and predict the real economy. These stem from new areas of mathematics and physics such as nonlinear dynamics, complexity and chaos theory. The results have been very promising, opened new venues and have contributed to a better understanding of the complex dynamics of economic systems. While we may never be able to perfectly model the economy or eliminate altogether the chance of a major economic downturn, for the next fifteen years many challenges for CeNDEF remain to help develop a new economics. I wish CeNDEF lots of aspiration and continuing success with this important endeavour.

Han van Dissel
Dean of the Faculty of Economics and Business

Complexity eco

The financial crisis of 2008 has changed the face of economics. This was poignantly expressed by the director of the ECB, Jean-Claude Trichet, at the opening of the ECB Central Banking Conference in 2010: *As a policy-maker during the crisis, I found the available models of limited help. In fact, I would go further: in the face of the crisis, we felt abandoned by conventional tools.*

The 'available models' were based on the fundamental assumptions that the economy is a near–equilibrium, almost linear system, that this is known to all agents, who have therefore fully rational expectations of future developments, and that any fluctuations are the effect of adverse or beneficial shocks which dampen out over time.

The economy turned out to be a highly nonlinear complex system.

Deregulation initiated in the 1980s as well as the wealth of new possibilities generated by digitalisation and global connectivity led to a pervading feeling of optimism. With hindsight, the long-term expectations of agents in the economy were often nothing else but simple linear extrapolations into the future; for fear of missing out, these expectations induced them to engage in investing, and hence in borrowing, on a grand scale.

Networks

A loan links the borrower to the lender; it can moreover serve the lender as the collateral of another loan taken out by him. In this way loans, and more generally financial instruments of all kinds, form a gigantic network, the counterparties figuring as the nodes. These days the financial network spans the globe, connecting the Danish housing market tightly to the New York stock exchange, or the industrial development of Thailand to Spanish unemployment. In the run-up to the crisis, the holders of US subprime mortgages turned out to be weak nodes: their failure to meet payment obligations set in motion a chain reaction of failing loans and breaking links. Though the risk of individual loans failing had been estimated reasonably correctly, the probability of many of these failing together had not. The chain reaction brought down hundreds of banks, of which Lehman Brothers was but the largest, and it almost brought down the global financial network.

The underlying mechanism works in many different and seemingly disparate contexts: ecologic food chains collapse, elastic materials deform, morning traffic jams. For each, the microscopic network structure translates into a macroscopic nonlinearity. The resilience of the system under normal stress does not extrapolate to high stress, and it collapses, deforms, or jams.

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The advent of heterogeneous expectation models

The vast increase in data and computing resources originating with the advent of electronic computers put the analysis of dynamic economic processes within reach of economic theory. Recognition of the fact that real economic agents act strategically suggested the hypothesis that their future expectations were always fully rational; less rational agents would be outcompeted by more rational ones and be eliminated by evolutionary pressure. The process would drive the economic system to a stationary state where all goods and assets would be priced correctly. This description of economic reality has been orthodox theory since the 1980s.

Unfortunately for theory, markets do not fit this argument, especially financial markets. Though competition on these markets is intense, they have always been characterised by boom-bust patterns, where long steady price increases are alternated by short violent price crashes.

In two highly influential articles published at the end of the 1990s, William (Buz) Brock and Cars Hommes elaborated the consequences of rejecting the rational expectations hypothesis. They showed that if agents are merely assumed to be competitive, acting as well as they can on the information available to them, the resulting model can explain boom-bust patterns and generally shows that price dynamics on financial markets are chaotic.

The beginning of CeNDEF

The Center for Nonlinear Dynamics in Economics and Finance (CeNDEF) originated from this cooperation. It was established in 1998 with the aid of an NWO Pionier grant awarded to Cars Hommes, backed by a Scientific Advisory Board consisting of Kenneth Arrow, William Brock, Jean-Michel Grandmont, Tom Sargent, Vernon Smith, Floris Takens and Howell Tong.

At the Center, an interdisciplinary team of scientists tries to understand the complex dynamics of real world economic systems. Starting point is the premise that economic agents are intelligent, but that they do not have a complete model of the economic world around them; rather they fend for themselves as best as they can, trying out rules and principles, sticking to them while they work and throwing them out for others if they do not. This basic idea is tested and tested again by looking precisely at peoples behaviour under carefully controlled laboratory conditions; by capturing it in mathematical models; and by estimating these on empirical data sets.

Long-term visio

Cars Hommes is Professor of Economic Dynamics: "CeNDEF started 15 years ago by an NWO Pionier grant. A good moment for some reflections and a future perspective. What have we achieved and where should we be heading in the future?

In the early days of CeNDEF, the focus had been on theory: complex systems, bounded rationality, heterogeneous expectations, behavioural and evolutionary modelling, etc., applying these concepts at first mainly to finance. In recent years we extended our scope to macroeconomics. The real challenge formulated in the CeNDEF grant proposal of 1998 was 'to empirically and experimentally validate' our theory. For me, it was a jump into the dark. But quickly it turned out that I was in very good company and I believe I can say that the research program has been very successful, having a high impact, thanks to more than 30 excellent researchers, postdocs and PhD students who contributed to the programme over the years.

We knew from the start that our theory is elegant, plausible and intuitive, but it now has been validated empirically and experimentally in numerous contributions. Heterogeneous expectations models with boundedly rational agents have been estimated successfully on many different financial and macro-economic time series, including stock prices, commodity prices, housing prices, exchange rates, inflation and output. Laboratory experimental data have shown the empirical relevance of bounded rationality and heterogeneous expectations in many different settings. Indeed we found that bounded rationality and heterogeneous expectations are almost everywhere. The key empirical and experimental finding is perhaps that in systems with positive feedback — like stock markets — agents do not learn easily and prices do not settle down quickly to a unique rational equilibrium, but rather fluctuate heavily, closely tracking almost self-fulfilling behavioural learning equilibria that are very different from the perfectly self-fulfilling rational equilibrium which is posited by mainstream economics.

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This has important consequences for policy and brings me to the most difficult task that still lies ahead of us. The current financial–economic crisis has awakened policy makers to the fact that an alternative approach is urgently needed to understand, manage and anticipate crises. The academic community is gradually, though perhaps slower than we hoped for, shifting its attention to alternative approaches. CeNDEF has contributed significantly to building an alternative behavioural complexity theory and it has convincingly shown that it is empirically relevant. Now is the time to start using this approach to design effective macroeconomic policies, to improve financial regulation and to conduct monetary and fiscal policies based on more realistic economic modelling. We have only just started: the next decade will see us tackling the big challenges that are still to come."

Cars Hommes

Experiments

Jan Tuinstra is Professor of Mathematical Economics. He graduated in econometrics in 1995 at the University of Groningen and received his PhD in mathematical economics from the University of Amsterdam in 1999 and has been affiliated with CeNDEF since its inception.

The focus of Jan Tuinstra's theoretical work is on bounded rationality and behavioural economics. In particular, he studies — in a variety of economic contexts — models of individual learning and models of evolutionary competition between different behavioural strategies. In addition, Jan Tuinstra works on models from industrial organization and on the effect and design of competition policy.

Jan Tuinstra

Since Jan Tuinstra joined CeNDEF he has devoted much of his research to running so-called 'learning-to-forecast' — laboratory experiments with paid human subjects. The goal of these experiments is to investigate how people form expectations in different economic environments, such as financial markets, commodity markets and macro-economic settings. These experiments provide useful insights into the behavioural rules used by humans when making decisions in dynamic economic environments. The behavioural rules identified in these laboratory experiments are subsequently used as an input in behavioural models of real world economic systems that are studied by the people at CeNDEF. The experiments therefore serve as a means to discipline how behaviour of individual economic agents is modelled.

Nonlinear data analysis

Cees Diks is Professor of Data Analysis and Economic Statistics. Before joining CeNDEF in 1999 he graduated in theoretical physics, obtained his Ph.D. in applied mathematics (nonlinear time series analysis) at Leiden university, and was a post-doctoral research associate at the University of Kent at Canterbury.

Cees Diks is an expert in the field of nonlinear time series analysis, a relatively new and active field that encompasses elements of both nonlinear dynamical systems and statistical data analysis. In his research at CeNDEF, he develops new statistical methods for analysing economic and financial time series, which take into account nonlinearity that may appear as a result of the bounded rationality of agents. He conducts fundamental demand-driven research, and is, for instance, involved in the CRISIS project, where a simulation model for the European Economy during the recent crisis is developed. Jointly with the Nederlandsche Bank (the Dutch Central Bank) he works on the estimation of housing price models in the presence of bounded rationality. With *Marcin Wolski* he works on methods for the detection of nonlinear causal relations between economic variables, and with *Juanxi Wang* on the development of early warning signals for financial crises.

Cees Diks

Nonlinear dynamics

Florian Wagener is Associate Professor at CeNDEF. He graduated in both engineering mechanics and mathematics at the University of Groningen and obtained a PhD in mathematics (nonlinear dynamics) at the same university. He held a position as post-doctoral research fellow at Warwick University, subsequently joining CeNDEF in 1999.

At CeNDEF he applies — with the aid of powerful numerical methods — geometrical and differential-topological concepts from the modern theory of dynamical systems to economic models with strong nonlinearities.

He works on understanding the dynamics in environments where there are few (rational) agents whose actions have long-lived consequences, as in pollution management or in the development of knowledge, and where the dynamics form a strong interplay with the strategic interests of the players. In such contexts, he studies the dependence on the optimal action schedules on the problem parameters, paying special attention to 'bifurcation points', where the nature and the long-term consequences of optimal actions change radically.

A second research strand focusses on situations with many interacting agents, and in particular in the theoretical implications of weakening the assumption of the agents being fully rational. These questions are practically relevant: in collaboration with William Brock and Cars Hommes he has shown that the proliferation of complex financial instruments destabilises financial markets if agents fail to be fully rational, a condition that is most likely fulfilled in practice.

Florian Wagener

New research directions

Maurice Koster is an expert on cooperative game theory; his research focuses on the problems of power measures and cost sharing. In the former field, he takes an axiomatic approach to developing a priori and a posteriori power measures for cooperative games, in particular voting games. These concepts allow to study the influence or power of agents interacting in a dynamic social network. With respect to the problem of cost sharing, he studies models where economic agents are involved in joint projects and have to share revenues and costs. The difficulty is to allocate these in such a way that contingent asymmetries between the agents are taken into account. His main research concern is to obtain axiomatic foundations of allocating investment costs in situations where these costs have a stochastic component.

Standard economic theory typically assumes that markets are characterized by anonymous traders, and that demand and supply clear at a single price. In reality, real markets are characterized by networks of long and short term trade relationships and price discrimination between different trading partners. At CeNDEF *Marco van der Leij* studies networked markets, in particular, how trade relationships are formed, how price information spreads through these trade networks and what policies would be best to manage these markets. He pays special attention to networks in financial markets, as these are a key in understanding the great financial crisis of 2007/2008.

Tiziana Assenza explores the role of heterogeneity (in its different meanings) in dynamic macroeconomic models. Once heterogeneity is explicitly taken into account it becomes difficult to think in traditional macroeconomic terms. She overcame this difficulty by devising an aggregate procedure, labeled the "Modified Representative Agent". In this approach, the time evolution of the agents' distribution is approximated through the analysis of the dynamics of a finite set of moments of the distribution itself. Moreover, she developed a model class in which the agent based structure is explicitly incorporated into a macroeconomic context. Such models can be used to analyze the effects of financial or monetary policy shocks on macroeconomic variables, as well as the way how heterogeneity affects and amplifies the effects of these shocks on the real economy.

Individual expectations play a central role in macroeconomics. The research of *Domenico Massaro* focuses on introducing individual bounded rationality and heterogeneous expectations in dynamic macroeconomic models. In particular, he evaluates alternative policy measures in dynamic feedback systems where macroeconomic variables and subjective expectations co-evolve over time. A salient

Maurice Koster | Marco van der Leij | Tiziana Assenza | Domenico Massaro

result is that standard policy advices may destabilize the economy in the presence of heterogeneous beliefs and evolutionary competition among them. An important part of his research concerns the empirical validation of individual expectation formation models, using data collected in laboratory experiments with human subjects as well as aggregate time series data.

The main research interest of *Te Bao* is experimental economics, with a focus on the interaction between individual expectations/decisions and aggregate market outcomes. In particular, he has conducted a number of 'learning to forecast' experiments; he found that markets with negative expectation feedback, like traditional cobweb markets, quickly converge to the rational expectation equilibrium, while markets with positive expectation feedbacks — speculative asset markets — have an intrinsic tendency to generate bubbles and crashes due to agents using trend following expectations. This result is robust against changes in the shape of the rational expectations equilibrium, as well as against variations in the experimental designs (quantity decision making vs. forecast, individual vs. team).

International cooperation is crucial in using natural resources and in solving environmental problems. It is even more so when it comes to global issues such as climate change, air pollution or biodiversity loss. *Tatiana Kiseleva* investigates the dynamic formation of international environmental agreements. In particular, she explores the role of threats in sustaining long-term cooperation in renewable resource use, showing that threats of reverting to non-cooperative behavior can be made more effective by optimizing the choice of additional instruments, such as the aggressiveness of harvesting technologies or the level of adaptation to changing environmental conditions.

Paolo Zeppini works at the interface of economic theory, environmental economics and innovation studies. He is mainly interested in the impact of technological change on environmental problems, the interplay between human behavior and ecological systems, and the economics and policy analysis of sustainable transitions. He develops simple tractable models of human behavior with heterogeneous agents, social interactions and multiple equilibria, using a multidisciplinary approach that builds on game theory, network theory, statistical

Te Bao | Tatiana Kiseleva | Paolo Zeppini | Marius Ochea

mechanics and evolutionary thinking. The main themes in this context are the emergence of cooperation in economic–ecological systems, the sudden transitions that characterize collective behavior, and ultimately the question whether the endogenous emergence of cooperation is a viable alternative to binding political agreements in the quest for a solution to our pressing global environmental problems.

The research area of *Marius Ochea* is broadly defined by the field of evolutionary game dynamics which sets out to investigate dynamical systems arising from evolutionary game theory. Evolutionary game theory studies the behavior of homo heuristicus, a player whose decision-making toolbox contains simple, adaptive rules to deal with interactive problems. Among the heuristics of interest are imitation rules, perturbed best-replies and learning through reinforcement. More recently, he is working on classes of adaptive heuristics — such as regret–matching and correlated fictitious play — that may lead to interesting dynamics on the joint set of actions or correlated play.

Dissertations

Henk van de Velden (2001)
An Experimental Approach to Expectation Formation in Dynamic Economic Systems

Gerwin Griffioen (2003)
Technical Analysis in Financial Markets

Sebastiano Manzan (2003)
Essays in Nonlinear Economic Dynamics

Sander van der Hoog (2005)
Microeconomic Disequilibrium Dynamics

Valentyn Panchenko (2006)
Nonparametric Methods in Economics and Finance: Dependence, Causality and Prediction

Pietro Dindo (2007)
Bounded Rationality and Heterogeneity in Economic Dynamic Models

Ilya Zovko (2008)
Topics in Market Microstructure

Peter Heemeijer (2009)
Expectation formation in dynamic market experiments

Marius Ochea (2010)
Essays on Nonlinear Evolutionary Game Dynamics

Tatiana Kiseleva (2011)
Structural Analysis of Complex Ecological Economic Optimal Control Problems

Paolo Zeppini (2011)
Behavioural Models of Technological Change

Te Bao (2012)
Experiments on Heterogeneous Expectations and Switching Behavior

Domenico Massaro (2012)
Bounded rationality and heterogeneous expectations in macroeconomics

Saeed Mohammadian Moghayer (2012)
Bifurcations of indifference points in discrete time optimal control problems

Roy van der Weide (2012)
The time-variation of volatility and the evolution of expectations

Grega Smrkolj (2013)
Dynamic models of research and development

PostDocs

Mikhail Anufriev
(2005–2008)

Tiziana Assenza
(2007–2009)

Stelios Bekiros
(2006–2007)

Andrea Cornea
(2008–2009)

Pim Heijnen
(2006–2008)

Zhenxing Huang
(2013–)

Marco van der Leij
(2011–)

Isabelle Salle
(2013–)

Dawit Zerom
(2002–2003)

Mei Zhu
(2009–2010)

A quote

"The work done at CeNDEF is an example of the approach I have in mind that will become the dominant approach in the future. Researchers there are combining new and old strategies to address fundamental questions. For example, their theoretical work is calibrated to reproduce many features of real-world data, but is based on heterogeneous agents with differing degrees of rationality, rather than on homogeneous agents. Their choice of assumptions is further governed by experimental and econometric work using field data. They study how changing the degree (e.g., the 'dial') of rationality creates dynamic patterns in their artificial economies, which are then compared to dynamic patterns observed in actual economies. They use complexity tools such as bifurcation theory to study these pattern-generating mechanisms analytically as well as computationally." *David Colander (2005)*

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