

7. EQUILIBRIUM, EXPECTATIONS & DYNAMICS

Subprogrammes:	EU FP7 Integrated Macro-Finance Modelling for Robust Policy Design (MACFINROBODS); EU Horizon 2020, Bridging the gap: from Individual Behaviour to the Socio-technical MaN (IBSEN); NWO Talent, Monetary and Fiscal Policy under Bounded Rationality and Heterogeneous Expectations; Institute of New Economic Thinking (INET), Heterogeneous Expectations and Financial Crises (HexFiCs); Marie Curie Innovative Training Network, Expectations and Social Influence Dynamics in Economics (ExSIDE).
Programme director:	Prof. dr. C.G.H. Diks
Section:	Quantitative Economics
JEL-Classification:	C, D, E6
Starting date:	1998
Website:	http://cendef.uva.nl

7.1 MEMBERS OF THE RESEARCH GROUP AND RESEARCH IN FTES

<i>Name</i>	<i>Title</i>	<i>Function</i>	<i>Total 2014</i>	<i>Total 2015</i>	<i>Total 2016</i>	<i>Funding</i>
Altaghlibi, M.	msc	guest	0,00	0,00	0,00	1
Amman, H.M.	prof. dr.	hgl	0,00	0,00	0,00	1
Anufriev, M.	dr.	guest	0,00	-	-	1
Assenza, T.	dr.	postdoc	0,16	0,16	-	1
Diks, C. (CeNDEF)	prof. dr.	hgl	0,50	0,50	0,50	1
Fang, H.	msc	phd	0,27	0,80	0,80	1
Goy, G.	msc	phd	-	-	0,27	1
Heemeijer, P. (CeNDEF)	dr.	guest	0,00	-	-	1
Hennequin, M.	msc	phd	-	0,27	0,80	1
Hommes, C.H. (CeNDEF)	prof. dr.	hgl	0,50	0,50	0,50	1
Hommes, C.H. (CeNDEF)	prof. dr.	hgl	0,32	0,35	0,35	2
Huang, Z.	dr.	postdoc	0,80	-	-	2
Huang, Z.	dr.	guest	-	0,00	-	1
Kiseleva, T.	dr.	guest	0,00	-	-	1
Kopányi, D.	msc	phd	0,53	-	-	1
Kopányi, D.	dr.	postdoc	-	-	0,27	2
Kopányi-Peuker, A.	dr.	postdoc	-	0,27	0,80	2
Koster, M.A.L.	dr.	ud	0,25	-	-	1
Koster, M.A.L.	dr.	uhd	-	0,13	0,08	1
Leij, M. van der	dr.	postdoc	0,33	-	-	2
Leij, M. van der	dr.	ud	0,20	-	-	2
Leij, M. van der	dr.	ud	0,17	0,50	0,50	1
Leur, M. van de	msc	guest	0,00	0,00	-	1
Li, H.	msc	guest	-	0,00	0,00	1
Linardi, F.	msc	guest	-	-	0,00	1
Lustenhouwer, J.	msc	phd	0,27	0,80	0,80	1

Makarewicz, T.	msc	phd	0,67	-	-	2
Makarewicz, T.	dr.	postdoc	0,13	0,80	0,53	2
Makarewicz, T.	dr.	postdoc	0,13	0,80	0,27	1
Massaro, D.	dr.	oz	0,80	-	-	2
Meertens, Q.	msc	guest	-	-	0,00	1
Mohammadian Moghayer, S.	dr.	guest	-	-	0,00	1
Negriu, A.	msc	phd	0,80	0,60	-	1
Negriu, A.	msc	guest	-	-	0,00	1
Ochea, M.I.	dr.	ud	0,33	-	-	1
Papana, A.	dr.	guest	0,00	-	-	1
Ramer, R.	dr.	guest	0,00	0,00	0,00	1
Ruiter, A.	drs.	guest	-	-	0,00	1
Salle, I.	dr.	postdoc	0,80	-	-	3
Salle, I.	dr.	postdoc	-	0,80	0,20	2
Sloot, P.	prof. dr.	hgl	-	-	0,07	1
Sniekers, F.	msc	guest	0,00	0,00	0,00	1
Stephan, S.	msc	phd	-	-	0,27	1
Tuinstra, J. (CeNDEF)	prof. dr.	hgl	0,50	0,50	0,50	1
Veld, D. in 't	msc	phd	0,53	-	-	2
Veld, D. in 't	dr.	guest	0,00	0,00	0,00	1
Wagener, F. (CeNDEF)	dr.	uhd	0,50	0,50	0,50	1
Wang, J.	msc	guest	0,00	0,00	0,00	1
Wang, H.-S.	msc	guest	0,00	0,00	0,00	1
Wolski, M.	msc	guest	0,00	0,00	0,00	1
Zeppini-Rossi, P.	dr.	guest	0,00	-	-	1
Zhu, M.	dr.	guest	0,00	0,00	-	1
Total 1st flow of funds			4,78	5,53	6,93	
Total 2nd flow of funds			3,78	1,95	1,08	
Total 3rd flow of funds			0,80	0,00	0,00	
Total 1st f.o.f. excl. Ph.D.'s			2,91	3,06	2,92	
Total 1st-3rd flow of funds			9,36	7,48	8,01	
Ph.D. students			2,94	2,47	2,94	

7.2 PROGRAMME DESIGN

The objective of the programme is the development of (mathematical) economic theory, focussing on the understanding of economic processes. The programme aims at developing models of economic behaviour in different areas of economics, including microeconomics, macroeconomics and finance. Emphasis is given to behavioural models of dynamic market phenomena.

The research group employs a multi-disciplinary approach. The models are studied both from a theoretical and a computational perspective, and the validity of the models is tested in laboratory experiments with human subjects as well as empirically using real data. The NWO-Vernieuwingsimpuls Information Flows in Financial Markets, the EU STREP project Financial Markets and Complexity and the NWO-VIDI programme *Structural Stability in Economic Dynamics* are part of the research programme.

The programme can be subdivided into five closely related and interacting research themes:

Equilibrium theory

Individual optimising behaviour of economic agents generates aggregate supply and demand of commodities, as a function of prices and individual expectations. In equilibrium supply and demand are

equal. Many types of equilibrium can be studied: partial versus general, competitive versus monopolistic, dynamic versus static, temporary equilibrium, single, representative agent as well as heterogeneous, interacting agents equilibria. The existence of equilibria is studied, as well as conditions for stability or instability of dynamic adjustment processes.

Game theory & Industrial organisation

This part of the programme focuses on modelling strategic behaviour of economic agents in markets with imperfect competition, such as duopoly and oligopoly. Equilibria in non-cooperative games (e.g. duopoly, oligopoly) as well as cooperative games (costs sharing, general equilibrium) are studied. Evolutionary games with heterogeneous, boundedly rational strategies competing against each other are also studied.

Expectations and learning

Bounded rationality models of expectation formation and learning schemes are becoming a serious alternative to rational expectations, which was the dominating paradigm until quite recently. The fully rational representative agent is replaced by a large *heterogeneous* population of boundedly rational interacting agents, who form expectations based upon time series observations and update their forecasting rules according to new observations and new information about market fundamentals. Conditions under which learning schemes converge to rational expectations or to a boundedly rational expectations equilibrium with excess volatility are investigated. Formation of expectations is studied in theory, in laboratory experiments with human subjects and in real markets.

Nonlinear economic dynamics

This part of the programme focuses on nonlinear complexity models of dynamic market phenomena. Are market fluctuations mainly caused by random exogenous shocks, or can endogenous nonlinear economic laws of motion explain (a significant part of) the fluctuations? Various deterministic and stochastic economic models are studied theoretically, computationally as well as empirically, attempting to explain the most important stylised facts observed in real economic and financial time series. Emphasis is given to *complex adaptive systems* where markets consist of a large population of agents selecting simple strategies according to their relative success in the recent past. In these evolutionary adaptive systems endogenous variables such as prices and agents' beliefs co-evolve over time.

Dynamic optimisation

Emphasis is given to dynamic optimisation problems in environmental economics, characterised by a conflict between economic benefits and ecological costs. Tools from nonlinear dynamics and bifurcation theory are employed to investigate non-convex dynamic optimisation problems. The main thrust is a structural analysis, that is, investigation of the global solution structure of dynamic optimisation problems and dynamic games. The qualitative changes of these solutions are studied under changes of the parameters. Geometrical methods, like bifurcation theory, normal form theory and perturbation theory, as well as numerical methods yield insights that hold not just at isolated parameter values, but for the complete parameter set.

7.3 PROGRAMME EVALUATION

This programme grew out of a mathematical economics program *Equilibrium and Dynamics*, led by Weddepohl, which was quite small until the mid nineties. The group was extended considerably at the end of 1998, thanks to an NWO-MaG Pionier grant awarded to Hommes, to set up the Center for Nonlinear Dynamics in Economics and Finance (CeNDEF). At that time the program changed from a small specialized mathematical economics program into a multi-disciplinary research program with an emphasis on economic theory, but also running laboratory experiments (in cooperation with Joep Sonnemans at CREED) to test behavioural theories and doing empirical work as well (in cooperation with Peter Boswijk at UvA-Econometrics), in particular nonlinear time series analysis, to test behavioural models empirically. Weddepohl retired in 2002 while Furth and Koster joined the group in the same year; from that point onwards, game theory has been included as one of the research

themes of the program. At the end of 2003, the CeNDEF postdocs Diks, Tuinstra and Wagener obtained tenured positions, ensuring the continuation of the research program. In 2009 the research program was ranked as one of the three top programs at the FEB by the VSNU “Visitatiecommissie” (Quality 4.5, Productivity 4.5, Relevance 5, Viability 5). From the report of the committee: “*The group (...) is developing very fruitful projects on highly topical current issues.*”

The publication record of the year 2016 is very good. The output was 11 articles in international refereed journals, amongst which publications in *Science*, *Journal of Applied Econometrics*, *Journal of Economic Dynamics and Control* and *Journal of Economic Behavior and Organization*. There were two PhD students, Hsin-Mien Wang and Jia-Ping Huang (co-supervised with the VU), that had a (co-)supervisor from the group, who defended their thesis successfully.

The programme is internationally established, as is shown by excellent citation statistics (e.g. according to the Science Citation Index (SCI) in 2016 more than 500 citations of published work by group members), many invited and several keynote lectures at international seminars, conferences and workshops by various members of the research group. In the IDEAS/RePEc ranking of Top 20% institutes (<http://ideas.repec.org/top/top.netherlands.html>), CeNDEF ranks as number 13, one position up from last year. This ranking contains faculties of economics and departments; among the small institutes of the order of a research group (up to 16 researchers) CeNDEF ranks 4th on the list.

In 2016, David Kopanyi joined the group as a PostDoc and Sanna Stephan and Gavin Goy joined the group as PhD students. Peter Sloot joined the group as a full professor.

In 2016 funding was secured for a tenure track position in Experimental Macroeconomics within the program. Recruitment has been initiated through the AEA job market in 2016, to be completed in 2017.

The evaluation can be summarized in the following **SWOT analysis** of the CeNDEF activities.

Strengths: international reputation as an excellent research group on nonlinear dynamics and complexity applications in economics and finance, high scientific impact (e.g., with both having been cited over 500 times (Web of Science), Brock and Hommes (*Econometrica* 1997), and Brock and Hommes (*JEDC* 1998), are two of the best cited journal articles co-authored by a Dutch economist), regular international visitors, active seminars and international workshops, own working paper series, frequently visited website, good facilities for computing and travel.

Weaknesses: relatively few publications in top mainstream journals, where multi-disciplinary work and non-mainstream approach such as agent-based modelling and complexity modelling are getting accepted only slowly; the number of links with practitioners and policy makers has been relatively low, but is now increasing.

Opportunities: development of UvA Graduate School in Economics; application of group-specific know-how to core economic problems, to demonstrate in this way the value of the programme's characteristic approach; developing more policy oriented research, e.g. through a new project on heterogeneous expectations in macro economics and monetary policy; for example, the NWO-complexity project is a research project jointly with researchers and policy makers at DNB.

Threats: A multidisciplinary group is likely to be handicapped when evaluated in a mono-disciplinary environment; and the complexity of the tools used may turn out to be an impediment at disseminating the research approach.

7.4 RESOURCES AND FUNDING

The budget received from ASE-RI every only covers on average one conference per researcher per year. A budget of the Faculty covers some of the costs for the Economics Colloquia; another budget of the Tinbergen Institute covers the costs of joint research seminars *Cooperative Behaviour, Strategic Interaction and Complex Systems - CSC* together with the VU mathematical economics group.

The group has been very successful in obtaining additional external funding. Joep Lustenhouwer is a PhD student since September 2014 funded by a NWO Talent project Monetary and Fiscal Policy under Bounded Rationality and Heterogeneous Expectations

CeNDEF is part of several European consortia that obtained grants: the EU COST action IS1104 “*The EU in the new complex geography of economic systems: models, tools and policy evaluation*”, and two INET projects, “*Coordination of Expectations*”, led by Roger Guesnerie and “*Heterogeneous Expectations and Financial Crises*”, led by Cars Hommes. The EU FP7-SHS Collaborative project (with 12 European partners) “*Integrated Macro-Financial Modelling for Robust Policy Design (MACFINROBODS)*” started in May 2014 is coordinated by Cars Hommes for UvA. A new EU Horizon 2020 project *Bridging the gap: from Individual Behaviour to the Socio-technical MaN (IBSEN)* has started in September 2015. In 2016 the application for a Marie Curie Innovative Training Network “*Expectations and Social Influence Dynamics in Economics (ExSIDE)*” was awarded, providing funding for 5 additional PhD positions within the program from 2017.

7.5 OUTPUT

Key publications

- Battiston, S., Farmer, J.D., Flache, A., Garlaschelli, D., Haldane, A.G., Heesterbeek, H., Hommes, C., Jaeger, C., May, R. and Scheffer, M. (2016). Complex Systems: Complexity theory and financial regulation. *Science* 351, 818-819.
- Diks, C. and Wolski, M. (2016). Nonlinear Granger Causality: Guidelines for Multivariate Analysis. *Journal of Applied Econometrics* 31, 1333-1351.
- Dockner, E. and Wagener, F. (2014). Markov perfect Nash equilibria in models with a single capital stock. *Economic Theory* 56, 585-625.
- Hommes, C.H. and Zhu, M. (2014). Behavioral Learning Equilibria, *Journal of Economic Theory* 150, 778-814.
- Linde, J., Sonnemans, J. and Tuinstra, J. (2014). Strategies and evolution in the minority game: A multi-round strategy experiment. *Games and Economic Behavior* 86, 77-95.
- Bao, T., Duffy, J. and Hommes, C. (2013). Learning, forecasting and optimizing: An experimental Study. *European Economic Review* 61, 186-204.
- Anufriev, M. and Hommes, C. (2012). Evolutionary selection of individual expectations and aggregate outcomes in asset pricing experiments. *American Economic Journal – Microeconomics* 4, 35-64.

Forthcoming

- Assenza, T. Brock, W.A. and Hommes, C. (2017). Animal spirits, heterogeneous expectations, and the amplification and duration of crises. *Economic Inquiry* 55, 542-564.
- Bao, T., Hommes, C.H. and Makarewicz, T.A. (2017). Bubble formation and (in)efficient markets in learning-to-forecast and -optimize experiments. *Economic Journal*.
- Hommes, C.H. (2017). From self-fulfilling mistakes to behavioral learning equilibria. In K. Nishimura, A. Vendetti & N.C. Yannelis (Eds.). *Sunspots and nonlinear dynamics: Essays in honour of Jean-Michel Grandmont*. (pp. 97-123). *Studies in Economic Theory*; Vol 31. Springer-Verlag.
- Kopányi-Peuker, A., Offerman, T. and Sloof, R. (2017). Fostering cooperation through the enhancement of own vulnerability. *Games and Economic Behavior* 101, 273-290.

- Schmitt, N., Tuinstra, J. and Westerhoff, F. (2017). Side effects of nonlinear profit taxes in an evolutionary market entry model: Abrupt changes, coexisting attractors and hysteresis problems. *Journal of Economic Behavior & Organization* 135.
- Wolski, M. and Van de Leur, M. (2016). Interbank loans, collateral and modern monetary policy. *Journal of Economic Dynamics and Control* 73, 388-416. (Published Dec. 2016)

Publications in numbers

Output type	Classification	#
Articles in journals	Refereed	11
	Non-refereed	0
	Professional	0
	Popular	0
Books or book chapters	Refereed	1
	Non-refereed	0
	Professional	0
	Popular	0
Conference proceedings		0
PhD theses		1

Article in journal - refereed

- Agliari, A., Hommes, C. H., & Pecora, N. (2016). Path dependent coordination of expectations in asset pricing experiments: a behavioral explanation. *Journal of Economic Behavior & Organization*, 121, 15-28.
- Anufriev, M., Bao, T. & Tuinstra, J. (2016). Microfoundations for switching behavior in heterogeneous agent models: An experiment. *Journal of Economic Behavior & Organization*, 129.
- Battiston, S., Farmer, J. D., Flache, A., Garlaschelli, D., Haldane, A. G., Heesterbeek, H., Hommes, C., Jaeger, C, May, R. & Scheffer, M. (2016). Complexity theory and financial regulation: economic policy needs interdisciplinary network analysis and behavioral modeling. *Science*, 351(6275), 818-819.
- Diks, C., & Wang, J. (2016). Can a stochastic cusp catastrophe model explain housing market crashes? *Journal of Economic Dynamics & Control*, 69, 68-88.
- Diks, C., & Wolski, M. (2016). Nonlinear Granger Causality: Guidelines for Multivariate Analysis. *Journal of Applied Econometrics*, 31(7), 1333-1351.
- De Groot Ruiz, A., Ramer, R., & Schram, A. (2016). Formal versus informal legislative bargaining. *Games and Economic Behavior*, 96, 1-17.
- Huang, J. P., Koster, M., & Lindner, I. (2016). Diffusion of Behavior in Network Games with Threshold Dynamics. *Mathematical Social Sciences*.
- Koster, M., Kurz, S., Lindner, I., & Napel, S. (2016). The Prediction Value. *Social Choice and Welfare*.
- Papana, A., Kyrtsou, C., Kugiumtzis, D., & Diks, C. (2016). Detecting Causality in Non-stationary Time Series Using Partial Symbolic Transfer Entropy: Evidence in Financial Data. *Computational Economics*, 47(3), 341-365.
- Salle, I., & Seppecher, P. (2016). Social Learning about Consumption. *Macroeconomic Dynamics*, 20(7), 1795-1825.
- Smrkolj, G., & Wagener, F. O. O. (2016). Dynamic R&D with spillovers: A comment. *Journal of Economic Dynamics & Control*, 73, 453-457.

Letter – refereed

Battiston, S., Farmer, D., Flache, A., Garlaschelli, D., Haldane, A., Heesterbeek, H., Hommes, C., Jaeger, C, May, R. & Scheffer, M. (2016). Response. *Science*, 352(6283), 302.

Book – refereed

Thuijsman, F., & Wagener, F. O. O. (Eds.) (2016). Advances in Dynamic and Evolutionary Games: Theory, Applications, and Numerical Methods. (Annals of the International Society of Dynamic Games; Vol. 14). Birkhäuser/Springer.

UvA Dissertation – externally prepared

Wang, H-M. (2016). R&D, patents and innovation: a differential game approach.