Behavioral Rationality and Heterogeneous Expectations in Complex Economic Systems

1

Cars Hommes University of Amsterdam Center for Nonlinear Dynamics in Economics and Finance (CeNDEF) Amsterdam School of Economics and Tinbergen Institute



Contents

	-		2			
			,			
•	:		•			
				ŧ		
			* •			
			•			
			1			
	List	ist of figures 2 pag				
	Pref	ace		XV		
			· · ·			
1	Inte	oductio		1		
T	1 1	Introduction				
	1.1	1 1 1	The discovery of chaos	3		
		1.1.1	Feonomic applications of chaos	4		
		1113	Expectations	5		
		1114	Bounded rationality and adaptive learning	7		
		115	Heterogeneity in complex adaptive rearning	8		
		1.1.6	Behavioral rationality and heterogeneous expectations	. 8		
	1.2	Adapt	ive expectations in a nonlinear economy	10		
	1.3	Ratior	al versus naive expectations	. 14		
	1.4	Adapt	ive learning	18		
		1.4.1	Cobweb learning-to-forecast experiments	19		
	1.5	Behav	vioral rationality and heterogeneous expectations	22		
	1.6	5 Financial markets as complex adaptive systems				
		1.6.1	Estimation of a model with fundamentalists versus chartists	28		
	1.7	Learn	ing-to-forecast experiments	30		
	1.8	Simpl	e complex systems	35		
	1.9	Purpo	se and summary of the book	36		
2	Bifu	ircation	ns and chaos in 1-D systems	39		
	2.1	Mono	tonic maps	40		
	2.2	The quadratic difference equation		43		
		2.2.1	Steady states and stability	43		
		2.2.2	Periodic and aperiodic time series	44		
	2.3	Bifurc	ations	46		
		2.3.1	Period-doubling bifurcation	47		
		2.3.2	Tangent bifurcation	49		

٠.

vii

		2.3.3	Transcritical bifurcation	52		
		2.3.4	Pitchfork bifurcation	52		
	2.4	Chaos	3	54		
		2.4.1	An example	55		
		2.4.2	Period 3 implies chaos	56		
		2.4.3	A chaotic invariant Cantor set	59		
	2.5	Lyapu	nov expogent	63		
	2.6	Chaos	and autocorrelations	66		
3	Bifu	rcatior	ns and strange attractors in 2-D systems	69		
	3.1	The H	lénon map	70		
	3.2	Bifurc	cations	73		
		3.2.1	Saddle-node and period-doubling bifurcation	74		
		3.2.2	Hopf bifurcation	76		
`	-	3.2.3	Breaking of an invariant circle bifurcation route to chaos	78		
		3.2.4	A codimension two bifurcation: degenerate Hopf			
			bifurcation	82		
	3.3	The h	orseshoe map	85		
	3.4	Homo	clinic orbits	88		
	3.5	Lyapu	nov characteristic exponents	93		
4	_ The	he nonlinear cobweb model				
	4.1	The co	obweb model	95		
	4.2	Naive	expectations	97		
	4.3	Ration	nal expectations	98		
	4.4	Naive	expectations in a complex market	99		
	4.5	Adapt	ive expectations	101		
	4.6	Linear	r backward-looking expectations	105		
		4.6.1	LBE with two lags	105		
		4.6.2	LBE with many lags	109		
	4.7	A beh	aviorally rational linear forecasting rule	113		
		4.7.1	Consistent expectations equilibrium	114		
		4.7.2	Sample autocorrelation (SAC) learning	115		
		4.7.3	Chaotic consistent expectations equilibrium	116		
	4.8	Learn	ing to believe in chaos	120		
5	The	cobwe	b model with heterogeneous expectations	130		
	5.1	Hetero	ogeneous expectations	131		
		5.1.1	Evolutionary selection and reinforcement learning	132		
	5.2	Ration	nal versus naive expectations	134		
		5.2.1	Local (in)stability of the steady state	138		
		5.2.2	A rational route to randomness	139		
		5.2.3	Saddle point instability and homoclinic orbits	143		
		5.2.4	Coexistence of attractors	146		

	5.3	Competing linear forecasting rules	148			
		5.3.1 Fundamentalists versus naive expectations	150			
		5.3.2 Contrarians versus naive expectations	152			
	5.4	Evolutionary selection and adaptive learning	155			
6	An a	asset pricing model with heterogeneous beliefs	159			
	6.1	The homogeneous benchmark with rational agents	161			
	· 6.2	Heterogeneous beliefs	163			
	6.3	Evolutionary dynamics	164			
	6.4	Forecasting rules				
	6.5	Simple examples	168			
		6.5.1 Costly fundamentalists versus trend followers	169			
		6.5.2 Fundamentalists versus optimists and pessimists	173			
		6.5.3 Fundamentalists versus trend and bias	176			
	6.6	An example with co-existing attractors	179			
		6.6.1 Fundamentalists versus conditional trend followers	180			
		6.6.2 A locally stable steady state and coexisting cycles and chaos	183			
		6.6.3 An endogenous mechanism for volatility clustering	188			
	6.7	Many trader types	190			
7	Emj	mpirical validation				
	7.1	The model in price-to-cash flows	197			
		7.1.1 Heterogeneous beliefs	199			
	7.2	Estimation of a simple 2-type example	201			
	7.3	Empirical implications	206			
		7.3.1 Bubble and crash dynamics	206			
		7.3.2 Response to a fundamental shock	208			
		7.3.3 Will the bubble resume?	209			
8	Lab	oratory experiments	211			
	8.1	Learning-to-forecast experiments (LtFEs)	213			
	8.2	Cobweb experiments				
	8.3	Asset pricing experiments	220			
		8.3.1 Benchmark simulations	221			
		8.3.2 Experimental results	223			
	8.4	Fitting a heterogeneous expectations model	224			
	8.5	Positive versus negative feedback experiments	228			
		8.5.1 Experiments with small shocks	228			
		8.5.2 Experiments with large shocks	231			
	8.6	Final remarks and future outlook	234			
	Bibl	liography	237			
	Inde	2X	251			