Price dynamics in equilibrium models

Tuinstra, J.

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Chapter 1

Introduction and Outline

Economic theory deals primarily with the existence of equilibria, i.e. prices at which market clearing occurs. If such equilibrium prices exist, the question arises how they are attained. The problem of how economic agents can coordinate on such an equilibrium has received much less attention than the problem of existence, but nevertheless is highly important. Indeed, if this problem cannot be solved satisfactorily, economic predictions and comparative statics based upon equilibrium analysis are strongly hypothetical. In this thesis we discuss, in a number of different equilibrium models, some different adjustment processes and try to gain some insights into out-of-equilibrium dynamics and the questions whether coordination on an equilibrium will in general be achieved or whether other dynamical phenomena may be encountered.

The best-known adjustment process in general equilibrium theory is the tâtonnement process, which is a very simple way to model the *law of supply and demand*. This law of supply and demand states that the price of a commodity will increase when demand for that commodity exceeds supply and that the price will decrease if supply exceeds demand. It is by now well-known (see Arrow and Hahn (1971)) that convergence of the tâtonnement process to an equilibrium price vector can only be guaranteed under rather restrictive assumptions on the aggregate excess demand functions. Moreover, it has been shown that for reasonable specifications of the fundamentals of the economy the tâtonnement process might lead to endogenous periodic and chaotic fluctuations of prices around an unstable steady state.

In this thesis the tâtonnement process and a number of other adjustment processes are studied. These models differ significantly from each other but they have some important characteristics in common. Firstly, most of them are models of *bounded rationality.* The problem of coordination on equilibria becomes relatively easy once one assumes unbounded rationality of economic agents, which implies that they have perfect knowledge of their economic environment, including the behaviour of all other economic agents and with this information are able to compute the, possibly complicated, equilibria. This assumption of unbounded rationality is much too demanding however and hence we focus on models where economic agents use some simple rules of thumb or models where they try to make some inference about their economic environment by looking at observations of certain economic variables. There is a "wilderness of bounded rationality" but we restrict this wilderness by considering rules of thumb that are "sensible" or "approximately rational".[1] Secondly, since price adjustment processes are in general highly nonlinear, we apply the methodology of *nonlinear dynamics.* In fact, we find that in most of our models the adjustment processes have typical nonlinear features, such as periodic and chaotic behaviour, just as can be encountered in the tâtonnement process. In the rest of this introductory chapter we will first briefly consider bounded rationality, then we will discuss the field of nonlinear economic dynamics and illustrate some of its features by considering a simple example of a tâtonnement process in a general equilibrium model. We will conclude with a brief outline of the remaining chapters in this thesis.

1.1 Bounded Rationality

Economics is rooted deeply in the theory of choice. Economic agents are decision makers choosing their actions, given some feasibility constraints, in a way that optimizes their objective function. The leading paradigm in economic theory states that economic agents are *rational* in the sense that they know the set of actions from which they can choose, they know the set of consequences associated to each of these actions and they have a complete preference ordering over these different consequences. The rationality assumption can be divided into two parts. Firstly, it is assumed that the agents exhibit individual rationality, that is, given the *perceived* feasibility constraints economic agents choose that action that optimizes their objective function. Secondly, the perceived feasibility constraints have to be *mutually consistent* over all individuals. Since the feasibility constraints for any economic agent are in part determined by the actions of other economic agents this implies that agents have to predict the actions of all other agents. The rationality assumption thus also applies to expectations with respect to the actions of other agents and culminates in the so-called *rational expectations hypothesis.* This hypothesis is indeed very demanding and really presumes *unbounded* rationality, since it requires that each agent exactly knows

[1] In the words of Sargent (1993, p.3): "I interpret a proposal to build models with 'boundedly rational' agents .... by expelling rational agents from our model environments and replacing them with 'artificially intelligent' agents who behave like econometricians."

how all other agents behave. It implies that all agents know the economic environment they are in and are able to compute equilibria and solve difficult optimization problems. It implicitly endows them with more ability and knowledge of the economic system, than economic theory can provide them with. Since the introduction of rational expectations by Muth (1961) and the introduction into macroeconomics by Lucas (1971) the rational expectations paradigm has been, until quite recently, the dominating paradigm in the modelling of expectations in economics.

The high requirements on knowledge, information gathering and computational abilities implied by the rationality assumption recently have lead a number of scholars to study models of bounded rationality (see for example the review by Conlisk (1996) and the books by Sargent (1993, 1998)). Several reasons (apart from common sense) for this can be identified. There is a lot of experimental evidence indicating that people are not as rational as is often assumed by economic theorists (see for example Thaler (1992)). Furthermore, the existence of deliberation and information costs is often ignored. As argued above, rationality requires much computational effort and information gathering. Since these are costly activities, they should be part of the decision problem of economic agents and it might well be "rational" to decide not to invest too much time and effort in being able to make the best decision if the trade off between the increase in deliberation costs is not matched by an equal increase in pay-off (in, for example, profit or utility). Proponents of the rationality approach have defended their position by using the "as if" argument, which states that economic agents are not really rational, but act *as if* they are. This is supported by the arguments that agents can learn how to behave rationally and those agents who do not will be driven out of the market since they will perform not as well as the rational agents. Another argument for rational expectations is that it disciplines the way in which behaviour of agents is modelled as opposed to the "wilderness of bounded rationality" which emerges if the rationality assumption is relaxed. These arguments implicitly suggest that we have to study models of bounded rationality and analyze whether in such models agents eventually behave as if they were rational. These models might also discipline the way in which we model bounded rationality.

Models of bounded rationality assume that agents are not unboundedly rational. Some models of bounded rationality assume that agents use very simple rules of thumb in order to make decisions. An interesting issue then is which of these rules of thumb performs better than others and will be imitated by other agents and drives out rules of thumb that perform badly. This is the subject of evolutionary models, such as models from evolutionary game theory (see e.g. Samuelson (1997), Vega-Redondo (1996) and Weibull (1995)). Other models of bounded rationality assume that agents are individually rational but boundedly rational with respect to their perceptions of the economy. They make inferences about their economic environment on the basis of some (incomplete) information set, for example by estimating some, possibly mis-specified, model of the economy. On the basis of this perceived model of the economy they are individually rational in determining their optimal choices.

There is another reason why the models of bounded rationality have received attention in the economic literature, particularly in models with multiple rational expectations equilibria. In these models bounded rationality is used as an equilibrium selection device, to determine which of these equilibria is most "likely". The models of bounded rationality, studied in this thesis are meant to provide more insights in how agents behave in real life and should therefore not be considered as models of equilibrium selection. Models of bounded rationality are an interesting object of study because we believe economic agents in fact behave boundedly rational.

1.2 Theory of Nonlinear Dynamics

In this thesis we analyze a number of dynamical systems, which in general will be nonlinear. As an approximation one could study the linearization of these dynamical systems around a steady state of the dynamics and consider local stability of this linearized system. However, this approach neglects important dynamical features of the original nonlinear system. In particular, the linearized system is only a valid approximation for the nonlinear system in the neighbourhood of the steady state. In contrast to the case of a linear system, in a nonlinear system a locally unstable steady state does not imply that the time paths will diverge since the nonlinearity of the dynamical system may cause (some or all of the) time paths to be bounded, which may lead to some kind of periodic or nonconverging but bounded behaviour.

In recent years the importance of the features of nonlinear dynamics has become gradually acknowledged in economic theory. In Section 1.2.1 we will briefly review the field of nonlinear economic dynamics and in Section 1.2.2 we will illustrate some important concepts from the theory of nonlinear dynamics, by studying a simple example of a tâtonnement process.

1.2.1 Nonlinear economic dynamics: a historical perspective

Nonlinear dynamic economic models can exhibit periodic cycles or even chaotic fluctuations. The question thus arises whether business cycles can be explained endogenously by nonlinearities in the underlying economic system. This would be an appealing alternative to the currently dominating paradigm that business cycles arise from exogenous shocks hitting an inherently stable (linear) system. In the last decades some progress has been made in this endogenous business cycle approach.

Among the earliest applications of the theory of nonlinear dynamics to economic models were the Cournot adjustment model by Rand (1978) and the growth models by Day (1982, 1983). These models have been criticized for the fact that agents in these models are behaving suboptimal and are in fact irrational. An important role in the development of nonlinear economic dynamics has subsequently been played by the overlapping generations model. Benhabib and Day (1982) and Grandmont (1985) have shown that in the overlapping generations model with utility maximizing agents, market clearing in every period and perfect foresight, periodic and chaotic behaviour can occur. These models have in common with the earlier contributions that they can be written as a one-dimensional difference equation. The existence of periodic and chaotic behaviour then requires that this difference equation is hump-shaped, which for the overlapping generations model corresponds to a strong conflict between income effects and intertemporal substitution effects. In recent years higher dimensional economic dynamic models have been studied and it appears that these models exhibit periodic and chaotic behaviour for more 'reasonable' specifications. Poincaré (1890) already pointed out that the existence of *homoclinic orbits* in such higher dimensional systems implies very complicated behaviour. De Vilder (1996), for example, has studied the overlapping generations model with capital and has shown the occurrence of chaotic behaviour in this model, for a specification of the model where income effects are dominated by substitution effects everywhere. Other recent examples of two dimensional economic models exhibiting strange behaviour are the cobweb model with heterogeneous expectations (Brock and Hommes (1997)), where evolutionary competition between different boundedly rational expectation rules leads to the existence of homoclinic orbits and the tâtonnement process with three commodities (Goeree, Hommes and Weddepohl (1997)) which for certain values of the speed of adjustment leads to chaotic fluctuations in prices.

The fact that periodic and chaotic behaviour can be consistent with utility maximization, market clearing and rational expectations or perfect foresight in a general equilibrium model can hardly be called surprising in light of the "anything goes" results by Sonnenschein (1973), Mantel (1974,1976) and Debreu (1974) who have shown that any set of continuous functions satisfying Walras' law and homogeneity of degree zero in prices, can be the excess demand functions for such an general equilibrium model with utility maximizing agents. One of the challenges for the field of nonlinear economic dynamics therefore lies in establishing that chaotic behaviour occurs for empirically relevant specifications of the fundamentals of the economy, such as utility functions and production technologies.[2]

The cycles and chaotic behaviour found in the overlapping generations model correspond to equilibria of a general equilibrium model and in that sense are not fundamentally different from the (stationary) equilibria economic theorists are used to studying. The recent upsurge of models of bounded rationality has lead to a renewed interest in the theory of nonlinear dynamics, from a different perspective. These models are populated by agents that behave adaptively: they make decisions on the basis of past observations. In general this leads to very complicated nonlinear dynamical systems, which often give rise to erratic disequilibrium behaviour. Most of the erratic dynamics in the models studied in this thesis are of this type. The main challenge for the theory of nonlinear economic dynamics lies in identifying the economic mechanisms that generate these erratic dynamics.

1.2.2 An example

We now briefly turn to a simple example of a tâtonnement process which features some of the dynamical phenomena that we will encounter throughout this thesis. Consider an economy with three commodities. The aggregate excess demand functions of the first two commodities are given by

$$\begin{aligned} z_1(p_1,p_2,p_3) &= \left(\frac{p_2}{p_1}\right)^{\alpha} + \left(\frac{p_3}{p_1}\right)^{2-\alpha} - 2 \\ z_2(p_1,p_2,p_3) &= \frac{p_1+p_3}{p_2} - 2, \end{aligned}$$

where $\alpha \neq 0$. The aggregate excess demand for the third commodity then follows from Walras' Law. The unique equilibrium price vector is given by $(p_1^*, p_2^*, p_3^*) = (1,1,1)$. Now take the third commodity as a numeraire ($p_3 = 1$) and consider the following tâtonnement process

$$\begin{aligned} p_{1,t+1} &= p_{1t} + \lambda z_1(p_{1t}, p_{2t}, 1) \\ p_{2,t+1} &= p_{2t} + \lambda z_2(p_{1t}, p_{2t}, 1), \end{aligned} \tag{1.1}$$

where $\lambda > 0$ is the speed of adjustment. Let us denote the tâtonnement process (1.1) by the mapping $F : I\!R_+^2 \to I\!R_+^2$. We are interested in the time path or orbit of an

[2]There is a large literature on detecting nonlinear structures in financial and economic time series (see for example Brock, Hsieh and LeBaron (1992)), which we will not touch upon in this thesis. The results to date are ambiguous. There has not been much evidence for low-dimension chaos in financial time series but the methods used are very sensitive to noise.

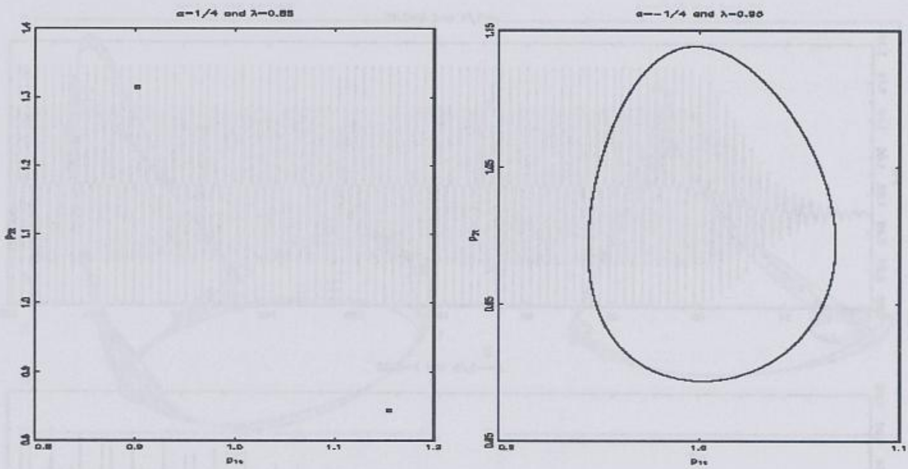

Figure 1.1: Long run behaviour for the tâtonnement process in the state space. On the horizontal axis p_{1t} and on the vertical axis p_{2t}. a) Period two orbit created in period doubling bifurcation. $\alpha = \frac{1}{4}$ and $\lambda = 0.85$. b) Quasi periodic cycle created in Hopf bifurcation. $\alpha = -\frac{1}{4}$ and $\lambda = 0.95$.

arbitrary initial price vector $\mathbf{p}_0$, under F, that is, the sequence of price vectors $\{F^t(\mathbf{p}_0)\}_{t=0}^{\infty}$ (where $F^t(\mathbf{p}_0) = F(F^{t-1}(\mathbf{p}_0))$ and $F^0(\mathbf{p}_0) \equiv \mathbf{p}_0$, for each $\mathbf{p}_0$) that is generated by the tâtonnement process. We are also interested in how the qualitative features of this orbit depend upon the parameters λ and α.

A first step in studying the dynamics of F is to consider a linearization of F around the equilibrium price vector $(p_1^*, p_2^*) = (1, 1)$. The linearized system is

$$\begin{pmatrix} \overline{p}_{1,t+1} \\ \overline{p}_{2,t+1} \end{pmatrix} = \begin{pmatrix} 1-2\lambda & \alpha\lambda \\ \lambda & 1-2\lambda \end{pmatrix} \begin{pmatrix} \overline{p}_{1t} \\ \overline{p}_{2t} \end{pmatrix},$$

where $\overline{p}_{it} \equiv p_{it} - p_i^*$. Let $\mu_1(\lambda, \alpha)$ and $\mu_2(\lambda, \alpha)$ be the eigenvalues of the linearized system (notice that they depend upon the parameters of the model). If both eigenvalues of this linearized system are smaller than 1 in absolute value then $(\overline{p}_{1t}, \overline{p}_{2t})$ will converge to $(0, 0)$. For the original system the steady state then is locally stable: for all price vectors in some small neighbourhood of the equilibrium price vector the adjustment process will converge to the equilibrium price vector. However, if at least one of the eigenvalues lies outside the unit circle the equilibrium is locally unstable. As one of the eigenvalues crosses the unit circle as a parameter varies, a so-called *bifurcation* occurs.[3] At such a bifurcation

[3]For a detailed analysis of the different local bifurcations, see for example the introductory texts on

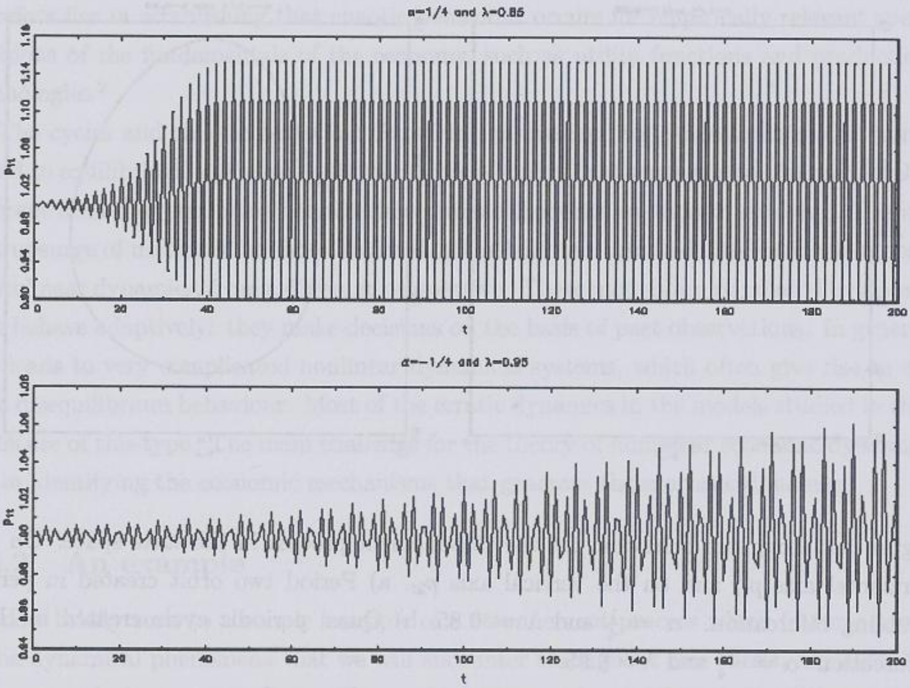

Figure 1.2: Time series of first 200 values of p_{1t} for a) $\alpha = \frac{1}{4}$ and $\lambda = 0.85$, and b) $\alpha = -\frac{1}{4}$ and $\lambda = 0.95$.

there is a *qualitative change in the dynamical behaviour* of the system. For example, the stability of the steady state changes and periodic cycles can be created. Figure 1.1 shows two important examples of what can happen at such a bifurcation. Figure 1.1.a) shows a period two cycle, for $\alpha = \frac{1}{4}$ and $\lambda = 0.85$ that is created in the *flip* or *period-doubling bifurcation* that occurs at $\alpha = \frac{1}{4}$ and $\lambda = \frac{4}{5}$. At these parameter values the eigenvalues are real and the smallest eigenvalue crosses the unit circle at -1 and a period two orbit of the dynamical system is created. The dynamical system then keeps on fluctuating between two price vectors. Figure 1.1.b) shows a closed curve which is invariant under F and which is created in the *Hopf bifurcation*[4] at $\alpha = -\frac{1}{4}$ and $\lambda = \frac{16}{17}$. At these values for the parameters,

nonlinear dynamics by Guckenheimer and Holmes (1983) or Kuznetsov (1995).

[4]In fact, the Hopf bifurcation describes the creation of limit cycles in continuous time systems. For discrete time systems such as ours, it would be more appropriate to refer to this bifurcation as the *Neimark-Sacker bifurcation.*

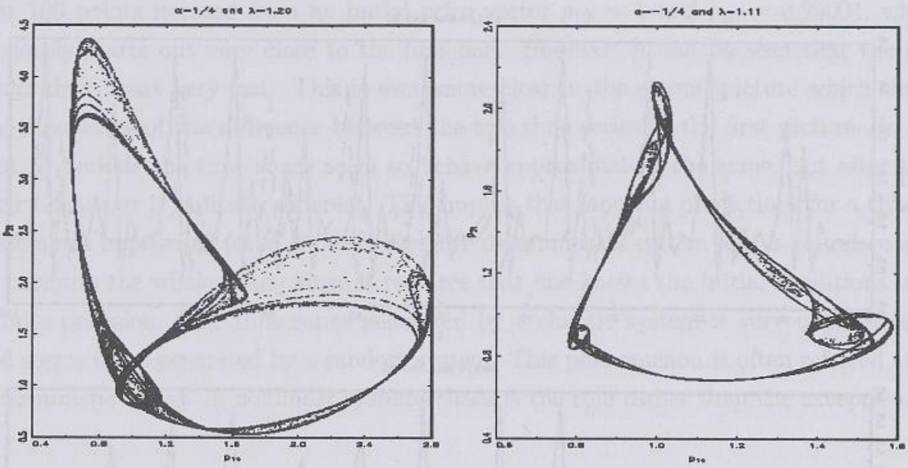

Figure 1.3: Strange attractors for the tâtonnement process. a) $\alpha = \frac{1}{4}$ and $\lambda = 1.20$, b) $\alpha = -\frac{1}{4}$ and $\lambda = 1.11$.

the eigenvalues are complex conjugates and are equal to 1 in absolute value.[5] The pictures in Figure 1.1 are constructed in the following way. An initial (nonequilibrium) price vector is chosen (in this case $p_{10} = 1$ and $p_{20} = 0.99$, which lies close to the equilibrium price vector) and F is applied to this initial price vector 6000 times and the last 5000 points (p_{1t}, p_{2t}) are plotted in the Figure. Figure 1.2 shows the corresponding time series for p_1. The pictures in Figure 1.1 correspond to the long-run behaviour of the tâtonnement process (1.1), and from these pictures it is clear that for a nonlinear system perpetual endogenous fluctations around an equilibrium are a generic feature, after this equilibrium has become unstable. Such a set of points that captures the (possible) limit behaviour of the dynamical system is called an *attractor*.

Important features of an attractor are that it is an invariant set (that is, if some orbit is "trapped" in the attractor it will move over the attractor forever) and that it attracts all points in some neigbourhood. An attractor is in fact a generalization of the concept of a locally stable equilibrium. In the case of a stable equilibrium this attractor consists of one point. Other examples of attractors are a stable periodic orbit of period k, where the attractor consists of k different points or a stable closed curve, where orbits move over

[5]The bifurcation values can be easily computed as follows. The eigenvalues of the linearized system are $\mu_{1,2}(\lambda, \alpha) = 1 - 2\lambda \pm \lambda\sqrt{\alpha}$. They are real if $\alpha > 0$ and the smallest of them then is -1 for $\lambda = \frac{2}{2+\sqrt{\alpha}}$. They are complex conjugates whent $\alpha < 0$, and then they lie on the unit circle when $\lambda = \frac{4}{4-\alpha}$.

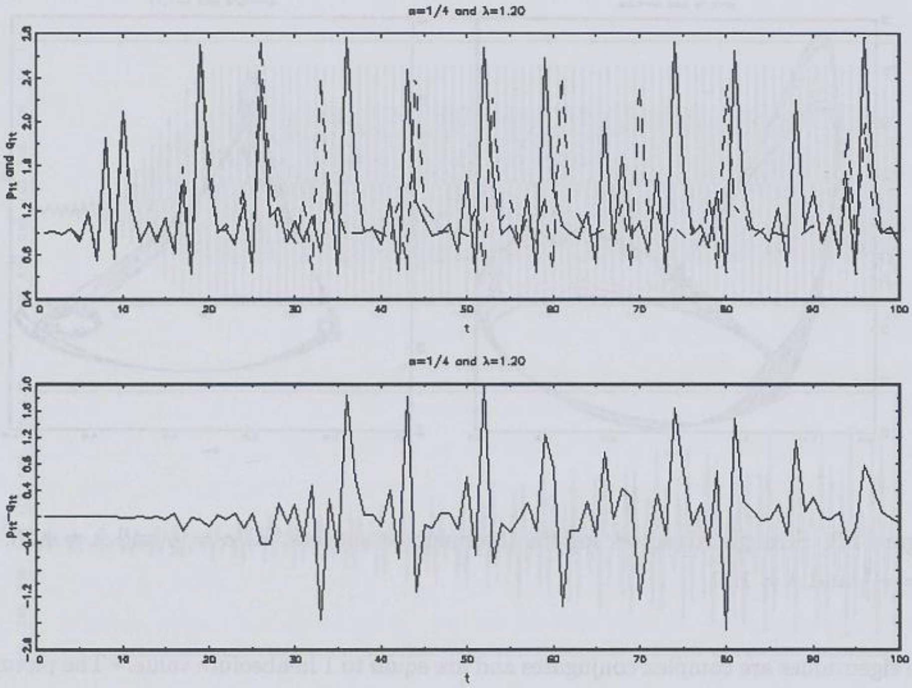

Figure 1.4: a) Two time series (for $\alpha = \frac{1}{4}$ and $\lambda = 1.20$) of first 200 values of p_{1t} for $(p_{10}, p_{20}) = (1, 0.99)$ (solid line) and for q_{1t} with $(q_{10}, q_{20}) = (1, 0.99001)$ (dotted line). b) Time series of difference $p_{1t} - q_{1t}$.

the closed curve quasiperiodically. Examples of these attractors are shown in Figure 1.1.

After the primary bifurcation of the equilibrium an infinite cascade of subsequent bifurcations can occur culminating in the existence of a *strange attractor*, with a complicated, fractal, structure. Examples are shown in Figure 1.3. From these pictures it is clear that the dynamics of the tâtonnement process for these parameter values behaves very erratically. These strange attractors can exhibit *sensitive dependence on initial conditions.* This concept can be clarified by considering time series corresponding to the strange and chaotic attractor in Figure 1.3.a). Two time series of orbits lying on this attractor and starting arbitrarily close to each other will follow quite different paths. To illustrate, consider Figure 1.4. In the first picture, two time series are shown. The time series with the solid line corresponds to the first 100 points iterated from the initial price vector $p_{10} = 1$ and $p_{20} = 0.99$, the time series with the broken line corresponds to the first 100 points iterated from an initial price vector $p_{10} = 1$ and $p_{20} = 0.99001$, which obviously starts out very close to the first one. However, it can be seen that the two orbits drift apart very fast. This is even more clear in the second picture which shows the time series of the difference between the two time series in the first picture. In the first 10 periods the time series seem to behave approximately the same, but after that their behaviour is radically different. This implies that long-run predictions for a chaotic system are impossible (even if one knows the deterministic system and is therefore able to compute the whole orbit) since it requires that one knows the initial conditions with infinite precision. The time series generated by a chaotic system is very unpredictable and seems to be generated by a random system. This phenomenon is often referred to as *deterministic chaos.* In nonlinear systems chaos is the rule rather than the exception.

1.3 Outline of the Thesis

In this thesis we consider equilibrium models with boundedly rational agents and study the out-of-equilibrium behaviour of these models. This leads us to the study of nonlinear economic dynamics and in fact, for most of the models studied, we find that dynamical phenomena such as periodic and chaotic behaviour that were described in the previous section can occur. In this section we will briefly outline the different chapters of this thesis.

Chapter 2 deals with the analysis of the tâtonnement process in a simple general equilibrium model. This chapter builds on earlier work by Weddepohl (1996) and Goeree, Hommes and Weddepohl (1997), who have studied the tâtonnement process in exchange economies with two and three commodities, respectively, and have shown that strange behaviour might occur. Since the tâtonnement process requires that prices are normalized, they choose the price of one commodity (the numeraire) to be equal to 1, just as was done in the example from the previous section. However, which commodity is chosen, or in general, which price normalization rule is used, turns out to be important for the dynamics of the tâtonnement process and therefore the normalization rule has to be chosen with care. We focus on the simplex as a normalization rule. This normalization rule has as an advantage that, when it is combined with the discrete time multiplicative tâtonnement process, prices automatically stay on the simplex (much like the sphere is invariant for continuous linear tâtonnement process (see Arrow and Hahn (1971))). In this way no information is lost in choosing the normalization rule. We focus on a general equilibrium model with three commodities which implies that the tâtonnement process is a two-dimensional nonlinear dynamical system. Since there is a wide variety of possible economies, our approach is to focus on symmetric economies first. It appears that different kinds of dynamic behaviour correspond to different kinds of symmetry. In particular, we can have *symmetry breaking bifurcations* and *coexistence of attractors.* This coexistence of attractors also appears for closeby asymmetric tâtonnement processes.

In the next two chapters we study the overlapping generations model. As was discussed in the previous section, this model has played an important role in the development of the theory of nonlinear economic dynamics. The papers by Benhabib and Day (1982) and Grandmont (1985) show that under perfect foresight and market clearing deterministic cycles and even chaotic behaviour can occur in the overlapping generations model. Chapter 3 deals with the close connection that exists between the appearance of such cycles with the existence of asymmetric equilibria in symmetric general equilibrium models of the kind that are analyzed in Chapter 2. These cycles are equilibrium cycles, that is, demand and supply along these cycles are in equilibrium. We construct some examples for which we can show that cycles of any period exist. Again it is of interest how agents can coordinate on such an equilibrium cycle (or on an equilibrium steady state). Chapter 4 deals with this problem of coordination and learning in the overlapping generations model. A simple overlapping generations economy with two generations and one commodity and boundedly rational agents is analyzed. The agents try to predict inflation rates by running a least squares regression on past prices or past inflation rates. The outcome of this learning process very much depends upon the way in which agents learn. If they learn on the basis of inflation rates beliefs may converge to some kind of limit belief, whereas the corresponding nonlinear dynamical system that determines the inflation rate still gives rise to periodic or chaotic behaviour. We call such a situation a *Beliefs Equilibrium,* since, given the class of beliefs they consider, the agents have no incentive to change their beliefs, although inflation rates might keep fluctuating in such a beliefs equilibrium.

In Chapters 2, 3 and 4 the focus has been on simple general equilibrium models with perfect competition. In these models it is unclear how prices are determined since all agents take prices as given. In Chapters 5 and 6 we study models of imperfect competition. Although we subscribe to the view that a real understanding of economic reality requires a general equilibrium perspective, the theory of general monopolistic equilibrium is quite complicated and includes a number of pitfalls. Hence, we will study the imperfect competition models mainly in a partial equilibrium context. Chapter 5 deals with what is probably the best-known partial equilibrium model of imperfect competition: the homogenous Cournot duopoly model. The question is whether agents can learn to play the Cournot-Nash equilibrium by using simple behavioural rules. We address this issue by developing a model of Cournot competition where there is evolutionary competition between these different rules. That is, there is a population of firms playing the Cournot duopoly game in pairs and the fraction of agents using a certain rule increases when average payoff corresponding to that rule is high in comparison with payoffs for other rules. We find that if agents switch relatively easy between different rules this evolutionary competition can generate complicated behaviour. In fact, for one typical example we are able to establish the occurrence of a *homoclinic bifurcation* between the stable and unstable manifolds of the equilibrium saddle point. This implies the existence of strange attractors for this model. Hence, evolutionary competition between a costly sophisticated behavioural rule and a cheap habitual rule of thumb leads to chaotic fluctuations. This kind of behaviour seems to be robust against considering different approaches to modelling evolutionary competition.

Chapter 6 reviews several models where firms set prices instead of quantities. The general setup is as follows. There are a number of firms producing a differentiated commodity. There is incomplete information in the following sense: firms do not have exact knowledge of the demand curve they are facing. Each firm acts as if it is a monopolist for the commodity he produces and neglects the effects from prices set by the other firms. Each firm then tries to estimate his demand curve and on the basis of this perceived demand curve sets a price for his product. This gives him new information, leading to a new estimate of the demand curve and subsequently to a new price. Notice that beliefs are misspecified, since firms do not take other firms prices into account. There might also be a misspecification in the structural form of the estimated relationship. We consider different learning models. One model assumes that firms have a lot of local information on the demand curve, it knows the amount it could have sold against last periods price and the price elasticity of the demand curve at that price. It uses this information (from the previous period) to estimate the demand curve. It can then be shown that this adjustment process converges to the Bertrand-Nash equilibrium if the cross-price effects are relatively small. If these become too large, periodic and complicated behaviour can arise. Such a learning process only uses the most recent observations. We also discuss the model by Kirman (1983) who considers a model where all previous observations on prices and quantities combinations (but not on price elasticities) are used to estimate the individual demand function. Prices and quantities then seem to converge to a so-called conjectural equilibrium. There is a continuum of these conjectural equilibria, and therefore prices and quantities in general do not converge to the Bertrand-Nash equilibrium.

Thus far all models that were considered showed that fluctuations in prices and quantities might emerge in flexible, competitive markets without any government intervention.

Chapter 7 demonstrates that electoral competition between political parties can also lead to these kinds of fluctuations or business cycles. In this chapter a simple general equilibrium model is developed that shows that the interaction between economics and politics can endogenously generate these political business cycles as an equilibrium phenomenon. The simple economy studied in this chapter consists of two sectors, a sector using high-skilled workers and a sector using low-skilled workers. There are two political parties, each representing workers from one of the sectors. In every period the political party that represents the biggest sector is elected. The elected political party is able to set wages in that period. An endogenous political business cycle can then develop in the following way. If the "high-skill" political party is in office it will raise wages above their equilibrium level, in order to raise (average) welfare for its platform. However, then a number of high-skilled workers have to seek employment in the low-skill sector and therefore the platform of the "high-skill" party decreases. As a result the "low-skill" political party may be chosen in some future period. This party will bring wages back to their equilibrium level which is beneficial for agents working in the low-skill sector, but also reduces their number and may cause the "high-skill" political party to be elected in the future again. In this way a political business cycle may emerge.

In this thesis we have considered a number of models from economic dynamics. These models are in general nonlinear and most of them assume that agents are boundedly rational. In general, the economic environment is too complex to be perfectly known. Agents therefore will often turn to simple habitual rules of thumb or adaptively updated mis-specified models of the world to choose the appropriate actions. Through trial-and-error learning or evolutionary competition between the different rules of thumb boundedly rational agents may still end up in some kind of equilibrium, such as the Beliefs-Equilibria discussed in Chapter 4, which in some sense is "approximately rational". On the other hand, these adaptive models open the door for complicated dynamics. In fact, chaotic dynamics seem to be the rule rather than the exception.