The Impact of Consumer Behaviour on Technological Change and the Market Structure

An Evolutionary Simulation Study

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He that will not apply new remedies must accept new evils: for time is the greatest innovator.

FRANCIS BACON (1561–1626)

Chapter 1

Motivation

1.1 Introduction

Consumer protection is a steadily recurring policy issue. In the newspaper one can regularly read about firms being accused of misleading information policy and competing unfairly. Further discussion arises, for instance, if planned fusions and take-overs are concerned, both leading to a monopolistic position. Economists are mostly interested in the effects of competitive structures on the allocational efficiency, whereas politicians aim at avoiding the exploitation of consumers by firms charging prices which seem to be above the appropriate level.

A field study by DEVINE and MARION (1979) in retail food markets has shown that in the markets where information was provided by publishing the food prices of all sellers in the newspaper, the level and dispersion of prices have been lower than in the other markets where the consumers had to compare prices themselves.

The situation, where consumers are assumed to have imperfect information is reflected in economic models following the approach of STIGLER (1961);[1] since consumers have to engage in costly price search activities, firms can charge different prices for the same product. The theoretical conclusion of the price search models usually corresponds to the experiment by DEVINE and MARION (1979): more consumers' information lowers the prices and their variance.

[1]Note that in many economic models perfect information is the standard assumption.

As for consumers, the implication seems to be obvious: more information and lower prices increase consumers' welfare. Better informed consumers and lower prices imply fewer profits. If it is assumed that firms differ in production techniques and costs, an increase in efficiency is expected, since high-cost firms are driven out of the market. In a dynamic environment, firms which intend to survive have to carry out research and development (R&D) in order to maintain or improve their positions in the market. Since this involves expenditures, SCHUMPETER (1943) argues that it is necessary for firms to earn positive profits. Not only is developing new technologies a strategy for firms to survive, it is also the basis for economic growth. Therefore, the redistribution of firms' profits may cause a trade-off between an efficient allocation on the product market and the rate of technological progress. Since these relationships seem to be important for economic development, a framework is provided in this thesis to study the influence of consumers' behaviour on economic growth.

In order to investigate the impact of consumers' information on the innovative activities of firms, two economic modelling approaches are combined in this study. Regarding the process of economic change, evolutionary models in the Schumpeterian tradition, like those by NELSON and WINTER (1982), exhibit much explaining power, but neglect both imperfectly informed consumers and heterogeneous prices. In order to analyse consumers' behaviour, a price search model is useful.[2] The combination of both approaches allows to analyse the impact of consumers' behaviour on economic change in a dynamic framework.

This thesis follows the works by Richard Nelson and Sidney Winter, especially the simulation model published by WINTER (1984). A weak point of his model, however, is that it does not take into consideration the influence of consumers' behaviour on firms.[3] To take account of the above-mentioned relationships between consumers' welfare and the rate of economic change, the simulation model will be combined with a price search model.

The hypothesis of this study is, that in addition to the determinants of the market structure, which mainly have been analysed in economic literature so far, such as rate of innovation, economies of scale, or life cycles, demand conditions influence

[2] Detailed arguments are presented in Sections 1.2 and 1.3.

[3] None of the well-known evolutionary economists takes this issue into account, see e. g. NELSON and WINTER (1982), DOSI et al. (1995), SILVERBERG (1987), KWAŚNICKI (1994, 1996).

innovative activities and, thus, the development of industry. Not only does the success of firms depend on expenditures on R&D, it also depends on the acceptance by the market. Pleschak et al. (1994), for instance, report in their guideline for innovative entrepreneurs, that one of the main reasons for new enterprises to go bankrupt is a lack of information concerning their sales potential.

The motivation to model the consumer sector in more detail is based on the following ideas. First, it is striking that evolutionary economists use the neoclassical core concept, namely the notion of (unit elastic) demand functions, to model consumers' behaviour. Second, and related to the first point, a pattern observed and described by Stigler (1961) turns the focus on the prices in a market. Instead of one market-clearing price, which is set by a Walrasian auctioneer, the process of price formation is explained. He argues that even in markets for homogeneous goods prices differ. Detailed evidence for this price dispersion was first given by Pratt et al. (1979) and Devine and Marion (1979). The search cost theory suggests that the non-degenerate price distributions in markets for homogeneous goods result from a lack of information on the consumers' part so that consumers have to spend money to obtain information about where to buy the product at a certain price.

The most interesting findings of the hybrid model are a trade-off between consumers' information and the rate of economic change. Another trade-off arises between consumers' information and the lifetime of firms. The simulation results show that it is imperative that the effects of improving consumers' information both on consumers' welfare and on the economy as a whole be considered. In the simulation, it turns out that ameliorating consumers' information is ambivalent. On the one hand, consumers benefit from low prices in the long run, but, on the other hand, economic progress slows down, i. e. the rate of innovation decreases. Additionally, firms are more likely to go bankrupt. Therefore, if improving consumers' information is concerned, one should decide carefully whether the advantages of lower prices outweigh a lower innovation rate and a higher bankruptcy rate. As for empirical evidence, the simulation results reveal that the model is able to reproduce many stylized facts.

The remainder of this thesis is organized as follows. In Chapter 1, the theoretical background is outlined in three parts. Since the model developed in this study combines two different strands of literature, the most important evolutionary economic literature is summarized in Section 1.2. It is, however, restricted to approaches that use simulation techniques. Section 1.3 refers to the main ideas of information economics, particularly to the theory of asymmetric information, which is of major interest here. In the last section of Chapter 1 it is explained how these two theories can be combined, and the motivation for examining this “marriage” is described.

Chapter 2 reviews the development of the literature concerning search costs. It will be shown how the idea works and how the models have been developed since the landmark paper by STIGLER (1961). In Section 2.3, the model that is chosen for this study to describe consumers’ search behaviour is presented.

In Chapter 3, a new evolutionary simulation model is developed. The aim is to study the impact of consumers’ behaviour on the development of the market structure in the framework of an evolutionary model. The impacts of consumers’ behaviour are analysed for a single firm as well as for the macroeconomic pattern that emerges from the relationship between the consumers’ search and the innovative behaviour of firms. The simulation data are presented in Chapter 4. The study concludes with Chapter 5.

1.2 Evolutionary Simulation Models

The interest in evolutionary economics is steadily growing. One has long been aware of one of the imperfections of neoclassical economics: the dynamic patterns of economic development cannot be explained appropriately.[4] One of the main topics in evolutionary economics is innovation as the driving force of economic development.[5] Much of the research on innovation goes back to the work by Schumpeter. These models differ from the neoclassical approaches in their explanations of economic growth. Usually, a distinction is made between growth and development (which is endogenous) and the sheer expansion of the economy (capital accumulation). That is, the Schumpeterian growth models of creative destruction give an explanation of

[4] For a survey of the industrial organization literature, see e.g. TIROLE (1988) and MARTIN (1993).

[5] That innovations are still of interest is demonstrated impressively by the recently published book by MOWERY and ROSENBERG (1998), which traces the history of technological innovations in the U. S. during the 20th century, offers explanations for the nature of innovations, and draws conclusions for the future development of the U. S. economy.

the growth *process* instead of regarding economic growth as exogenous or as "Solow residual".[6] As maintained by Dosi et al. (1997, p. 3), "[b]oth the 'structure-conduct-performance' and the 'new industrial organization' (IO) approaches concentrated their attention on essentially static analyses of the structure of industries."[7] New techniques have been developed and applied to study the complex, non-linear relationship between market structure, conduct (e. g. price, R&D, investment), and performance (e. g. efficiency, profits), and particularly the relationship between innovation and market structure.

In their book *An Evolutionary Theory of Economic Change*, Nelson and Winter (1982) made the ideas of evolutionary economics popular, which take into account that there are non-linear relationships in economic processes and that time matters, i. e. the time path of economic developments is irrevocable. This book is still influential for two reasons. First, it summarizes many ideas and present an approach to deal with economic growth. Second, the authors put forward the use of simulation techniques as a relatively new method in economics.

1.2.1 Evolutionary Approaches

Evolutionary economics is a wide field of analysis and is still a strand of science that underlies an evolutionary process itself. This concerns the fields of application as well as the methodology. Recently, attempts have been made to systematize various fields of application, such as technological change, evolution of institutions, and policy issues. These are discussed, for instance, by Lehmann-Waffenschmidt (2002) and Erlei and Lehmann-Waffenschmidt (2002). The roots of evolutionary economics, the methodological variety, applications and discussions are described in detail in Herrmann-Pillath and Lehmann-Waffenschmidt (2002).

Although there are analogies to the biological theory of evolution, some demands have to be met for an evolutionary theory to be applied to economics since not all

[6] For a survey of the innovation literature, see Reinganum (1989). An overview of Schumpeterian growth models using a general equilibrium approach is given by Dinopoulos (1996) and Aghion and Howitt (1993).

[7] The "structure-conduct-performance" paradigm was introduced to the industrial organization literature by Bain and Mason in the 1950s, see Tirole (1988, p. 1).

processes observed in biology are appropriate for socio-economic systems. Therefore, it first seems to be vital that the term "evolutionary" be defined. According to Witt (1987, 2001b), a theory is evolutionary if it satisfies the following properties. An evolutionary theory is dynamic, historical, and self-transformational. This means that it is able to represent the dynamics of a process, deals with irrevocable and path-dependent historical developments, and "includes hypotheses relating to the source and driving force of self-transformation" (Witt (2001b, p. 5)). Nelson (1995) also suggests that a theory should meet some requirements in order to be called evolutionary. An evolutionary theory concerns one or more variables that change over the course of time. The theory should include a process driving these changes, i. e. a mechanism which is responsible for the change (e. g. selection and mutation). The observed variables are influenced by random disturbances, so that the evolutionary system is neither deterministic nor totally random. A typical application for an evolutionary economic model is economic development in order to explain the process of technological change, assuming heterogeneous firms. Gradually, firms with certain characteristics systematically have higher survival rates. There is a selecting unit (the market) that endogenously generates a distinctive structure of the industry. The selection criteria are of main interest, i. e. the reason(s) why some firms are selected and others are not. Without knowing this, the theory is useless because it does not explain anything and, therefore, cannot predict any outcome. Another evolutionary issue is learning. If the firms are able to learn about strategies, they can modify their probability distribution of choosing a "survivor-strategy".

Schumpeter, Hayek, and Alchian, who are frequently cited, are regarded as predecessors of evolutionary approaches in economics. Nelson (1995) begins his survey about *Evolutionary Theorizing* with a passage from Alfred Marshall's *Principles of Economics* to demonstrate that the desire to understand economic change is at least 100 years old. One of Marshall's ideas was to borrow from biological concepts and transform them to explain economic phenomena. Further roots can also be found in other disciplines, such as (socio-)biology or psychology.

The extent to which biology is helpful is still a point of discussion. Nelson (1995) argues that on the one hand, the notion of equilibrium and optimizing behaviour is not very convincing if continuous changes are analysed. Concerning the evolutionary process in biology, however, there are concepts which are useful for studying economic change. The biological development of species, for instance, is a dynamic and path dependent process. To refer to an equilibrium in this context seems to be unreasonable because there is continuous change, and individuals and populations die or survive according to a selection mechanism. One important stimulus for evolutionary theorizing is the better understanding of complex dynamic systems.[8] The rapid adaptation of evolutionary models is mainly induced by the development of mathematical tools and of the computer technology so that simulation models can be constructed and computed, and data processing can be done with increasingly less effort.

One of the most important authors who contributed to the analysis of economic change is Joseph Alois Schumpeter (1883–1950). His books *Theorie der wirtschaftlichen Entwicklung* (1911) and *Capitalism, Socialism, and Democracy* (1943) are widely cited and have still a remarkable influence on the development of (evolutionary) growth models.[9] Another landmark is *An Evolutionary Theory of Economic Change* by Richard Nelson and Sidney Winter, published in 1982. Nelson and Winter (1982, p. 39) say that "the term 'neo-Schumpeterian' would be as appropriate a designation for our entire approach as 'evolutionary'."

In the models of the Schumpeterian tradition the key actors are the firms. The firms' actions are evaluated using a measure of "fitness", often called "performance". According to Nelson and Winter, the behaviour of firms is characterized by "routines".[10] The routines are decision rules that underlie the process of learning. Nelson (1995, p. 69) differentiates three types of routines. The first type are standard operating procedures that determine how and how much a firm produces under various circumstances if the firm's possibilities are given (e. g. the technology). The second type are routines that determine the investment behaviour of the firm, where the investment functions can depend on different variables, such as profits and performance.

[8] For an application, see e. g. Anderson et al. (1988).

[9] Although many approaches to model technological change are traced back to Schumpeter, Witt (2001b) points out that Schumpeter himself never made an attempt to construct an evolutionary model.

[10] "We use 'routine' in a highly flexible way, much as 'program' (or, indeed, 'routine') is used in discussion of computer programming. It may refer to a repetitive pattern of activity in an entire organization, to an individual skill, or, as and adjective, to the smooth uneventful effectiveness of such an organizational or individual performance." Nelson and Winter (1982, p. 97).

The third type of routines determines how the firm searches for better alternatives, where the search behaviour affects all routines.

The firms compete in the same market. Therefore, not only does the performance of a firm depend on its own actions, it also depends on the behaviour of the other firms. R&D decisions and success vary between firms and constitute differences in the performance and, hence, in the lifetime and size of firms. Depending on the outcome of the search process and on the firm's performance, some of the routines may be modified. Such a dynamic stochastic system is usually modelled as a Markov process.

The macroeconomic patterns that arise are generated by the model and based on microeconomic behaviour. This means that there is a process which governs economic change, and the dynamic of that process is caused by individual behaviour. The results are generated endogenously and are path-dependent. Therefore, the behaviour of the driving forces of economic change can be studied, and it becomes clear why diversity among firms and technologies can be observed.[11] Depending on the characteristics of a market, different patterns arise.

A related question is how firms will react to changes in their environment. Above, firms have been characterized as carrying out several routines that are determined in the short run and modified by search activities. Routines, indubitably, play an important role.[12] Depending on firm characteristics and on the environment, the capability of firms to adjust to new conditions may be decisive. In some industries, large changes in consumer demand or input conditions (e. g. oil crises) have tremendous effects. Incumbent firms disappear and many new firms enter the market, whereas in other industries the incumbents can adjust their technologies and the market structure hardly changes.

That firms follow routines is an expression of their limited capabilities.[13] MUELLER (1989), for instance, has shown that between firms with similar equipment there are persistent differences in the performance (that is why it is difficult to imitate the

[11] Empirical findings are presented, for instance, in RUMELT (1991), MUELLER (1989), and METCALFE (1988).

[12] NELSON (1995, p. 78) remarks that if the firms were biological entities they could not react to changes because their behaviour would be predetermined by the genes that cannot be altered.

[13] For an extended discussion of routines, see WITT (2001a).

innovator successfully). One possibility of explaining these differences is that the routines are combined differently.[14]

According to NELSON (1995, pp. 79), there is evidence that the introduction of new technologies makes entry barriers break down, new firms enter the market, and old ones die. Furthermore, it has been observed in some cases that there are periods in which different technologies are dominant and supported by special institutions. This can be a relatively stable situation. If a change occurs, the industry becomes "mixed up", adopts the new technology with the help of new firms, and new institutions evolve.[15]

Two of the most important features of industry structure are market entry and exit. The rates of entry and exit have a direct impact on the development of market structure. A necessary condition for market entry is that a firm expects positive profits. This is valid for existing markets, in which several incumbents or a monopolist are operating as well as for a new market that is going to be created by the innovation of the founder.

Positive profits may have different causes. TIROLE (1988, p. 305) argues that "[i]n order to explain why the profit rate is systematically greater in certain industries than in others, some type of restriction to entry must exist in these industries to prevent other firms from taking advantage of the profitable market situations." These restrictions, known as "barriers to entry", have different causes, such as increasing returns, sunk costs, information or cost asymmetries,[16] and protect the incumbent(s) up to a certain degree from (more) competitors. The incumbents can also prevent entry by applying costly strategies concerning prices, quantities or other factors, such as advertising, product differentiation, or R&D expenditures. In addition, these strategies can be used to drive a rival out of the market.[17]

[14]This is further examined by the competence-based theory of the firm, see e.g. CANTWELL (1998), WITT (1998), and SACHWALD (1998).

[15]For the role of institutions, see e.g. YOUNG (1998) and NORTH (1990).

[16]Although non-economic barriers to entry exist, they are not considered here. These are legal or administrative barriers to protect certain industries for political reasons.

[17]How market evolution is influenced by R&D expenditures is demonstrated in a relatively simple model by REINGANUM (1985). In a game-theoretic framework she develops a model of creative destruction. An extension of her model is provided by IOSSO (1993).

To sum up, all the evolutionary models following the tradition of Schumpeter in one or another way, are designed to explain the causes and driving forces of economic change. The most important changes are improvements of the production technology either through innovation or the diffusion of new technologies through imitation. Typically, imitation and innovation are processes whose outcome is uncertain. Therefore, predictions are made as probability distributions instead of point estimates. The models offer explanations for the factors influencing economic change, which can be attributed to the individuals who participate in the market process. Since economic change is a major determinant of economic growth, these models can also be subsumed under the strand of economic growth models.

1.2.2 Simulating Social Phenomena

Hayek (1948a, p. 68) mentioned that it is necessary to "construct hypothetical models in an attempt to reproduce the patterns of social relationships which we know in the world around us."[18] This can be done, for instance, by creating a model that can be simulated on a computer. There are, however, additional reasons to use simulation techniques as a scientific method.

Computational methods have become increasingly interesting as computers developed. In the natural sciences, computer techniques have been immediately adopted as useful tools. In the social sciences, however, skepticism is vanishing only slowly. JUDD (2001, p. 1) states that "[t]he increase in computer speed is one reason why we see these new applications, but an equally important reason is the development of new algorithms." He also shows some fields of application in the introduction to the special issue of *Economic Theory* on "Computation and Economic Theory."

That computer programmes are able to solve complex tasks has early been recognized. Some of the pioneers in economics are, for instance, Stuart Kauffman, Christopher Langton and many others connected to the Santa Fe Institute, where, inter alia, evolving complex systems have been studied and the discipline of artificial intelligence has been developed.[19]

[18] Cited from KIRMAN and VRIEND (2001, p. 466).

[19] See e.g. ANDERSON et al. (1988). A very entertaining story of the people and events that influenced this development is given by WALDROP (1992).

In general, a computer programme is useful if an analytical solution to an economic problem cannot be obtained. Instead, numerical solutions provide insights into the problem, particularly if there are non-linear relationships or if there is a complex dynamic system. The application of computational methods can also have a positive effect on the scientific atmosphere. TESFATSION (2001), HEGSELMANN and PEITGEN (1996), and TROITZSCH et al. (1996) point out that, for instance, conceptionally integrated socio-economic theories can be formulated, and connections within the social sciences can be established. In this way, the computational approach can unite social scientists of many disciplines because the computer language establishes a common base for communication.[20]

In the introduction to a special issue on "Agent-based Computational Economics (ACE)" in the *Journal of Economic Dynamics and Control*, TESFATSION (2001) argues that the ideas for the ACE approach can already be found in the works by Smith and Hayek (self-organization) and Schumpeter and Alchian (Darwinism, evolving systems). But they did not have the possibility of using computers. TESFATSION (2001, p. 282) divides the ACE approaches into those that "demonstrate *constructively* how these global regularities might arise from the bottom up, through the repeated local interactions of autonomous agents acting in their own perceived interest" and normative approaches "as computational laboratories within which alternative socio-economic structures can be studied and tested with regard to their effects on individual behaviour and social welfare."

Following TESFATSION (2001), computational approaches can be the basis for economic models, which are built on individual behaviour and aim at finding patterns at a macro level. Already existing theories can be tested, refined and extended. A computer model allows to study the behaviour of heterogeneous agents and interactions between the agents and between agents and their environment. Behavioral rules can be adjusted to different environments and problem structures. The process of self-organization of individual behaviour can be studied. A possible selection mechanism can be applied to individuals instead of whole populations, where, for instance, the evolution and co-evolution of strategies can be explained. The model results emerge without any intervention from outside. Computational methods are

[20] Pleas for using computational methods in economics can also be found, for instance, in JUDD (1998) and VELUPILLAI (2000).

expected to lead to new insights, although one has to be aware of its limitations. The choice of the parameter values may influence the results substantially, and the model may be sensitive to the rules that determine the transition from one period to another as well as to the behavioural assumptions of the individuals. On the other hand, a computer model offers the possibility of analysing these effects exactly.

Prominent advocates following the approach of NELSON and WINTER (1982) and using simulation models which are mainly modifications of WINTER (1984), are, for instance, KWAŚNICKI and KWAŚNICKA (1992), KWAŚNICKI (1994, 1996), SILVERBERG (1987), ANDERSEN (1997), CHIAROMONTE and DOSI (1993), DOSI (1988), DOSI et al. (1994), DOSI et al. (1995), DOSI et al. (1997), and DOSI and MARENGO (1999). Inspired by several visits at the MERIT (Maastricht Economic Research Institute on Innovation and Technology) and the book by NELSON and WINTER (1982), KWAŚNICKI and KWAŚNICKA (1992) and KWAŚNICKI (1994) set up an own evolutionary simulation model of industry development similar to the work by NELSON and WINTER (1982). They extend, for instance, the financial possibilities of firms and their investment strategies. Additionally, they analyse the competition of heterogenous but functionally equivalent products on the market as proposed by GERYBADZE (1982).[21] KWAŚNICKI (1994, pp. 110) also considers the important role of the determination of product price(s). SILVERBERG (1987) implements different strategies of markup pricing. KWAŚNICKI (1996) analyses the impact of several types of innovation, concerning unit cost, the product's performance, and the productivity of capital on the price distribution. ANDERSEN (1997) uses simulation techniques to study the growing complexity of an economic system accounting for structural economic change. His ideas are also based on the work by NELSON and WINTER (1982).[22]

CHIAROMONTE and DOSI (1993) build a two-sector simulation model where the sectors are vertically connected. They show the effects of the micro behaviour on the aggregate dynamics concerning variables, such as income and labor productivity. CHIAROMONTE and DOSI (1993, p. 117) state that their economy is self-organizing "despite, or *because of*, disequilibrium micro behaviors."

[21]Another extension of the approach of NELSON and WINTER (1982) by product innovations is VALENTE (1998, 1999).

[22]See e.g. ANDERSEN et al. (1996).

Dosi et al. (1994), Dosi et al. (1997), and Dosi and Marengo (1999) claim, for instance, to investigate the constraints that influence the development of organizational and technological patterns. Dosi and Marengo (1999, p. 17) state that "[p]atterns of innovative activities are the result of complex interaction between micro-processes of learning and adaptation and competitive selection forces." They try to figure out how asymmetric firm-size distributions as well as sectoral and regional differences in innovative behaviour emerge. An analytical formulation of their ideas and some simulation results for a multi-sector economy are presented by Dosi et al. (1995). An empirically oriented survey on the microeconomic basics of innovative activities and their effect on the development of market structure is given by Dosi (1988).

Several approaches of modelling evolutionary growth processes, such as replicator dynamics, Master equations and the Polya urn approach, or the concept of evolutionary stability are outlined in Silverberg and Verspagen (1995) and Silverberg (1997). For the applicability of mathematical methods in general, see Silverberg (1988).

1.3 Economics of Information

In his seminal paper Stigler (1961, p. 213) mentions that "knowledge *is* power." In reality, there is hardly any situation in which an economic agent has perfect or almost perfect information. The literature on information economics deals with situations, in which agents either have incomplete or imperfect information, the latter meaning that the agents are uncertain about their situation when they have to make a decision. In this study, the model employed is one of incomplete information. An example is the insurance market, where the person who intends to have an insurance contract (e. g. a health insurance) knows more concerning his risk than the insurance company (e. g. their health status or the risk of falling ill due to drug abuse). In the context of this study the consumers are incompletely informed. They have to search because they do not know the product price charged by a seller. Each seller, instead, knows this price. Therefore, information is asymmetric. According to Phlips (1988, p. 3), incomplete information has the following effects.

> "As this example is meant to suggest, recognition of informational asymmetries and the strategic possibilities they engender can yield models that begin to capture the richness of behavior that marks the real world. This is the great advantage of these methods: they permit us to model, and thereby start to understand, phenomena that made no sense in terms of complete information analyses or one based on incomplete but symmetric information (uncertainty)."

Among many others, the economics of information deals with moral hazard (health care), principal-agent relationships (behaviour of firm managers vs. owners), adverse selection (market for used cars), signalling (job market), screening, and incentives (insurance). Examples in the context of industrial organization are collusion in oligopolies and the establishment of barriers to entry by pricing strategies.

According to Fishman and Rob (1995), the models of price dispersion differ from the traditional approaches of the industrial organization literature (e. g. from modern dynamic approaches, such as Hopenhayn (1992) and Jovanovic (1982)) in many aspects. The industrial organization literature explains differences, e. g. in firm size, profits, and sales-profit ratios, by referring to the supply side, i. e. supposed reasons for the observed heterogeneity are varying firm characteristics or the market structure. Instead, the search cost approach traces the reasons back to the demand side. Incomplete consumers' information causes the firms' market power insofar as the firms are able to charge prices above the competitive price, which may result in differences across firms and industries. By assuming positive search costs of the consumers, it becomes possible to regard the market structure as endogenous in dynamic models.

There is much criticism concerning the concept of competitive equilibrium that assumes complete information. One critic is that the model does not explain how the process of price formation works, particularly without the existence of a Walrasian auctioneer. Already von Hayek (1945) emphasized that since information is being dispersed among people, it can never be considered complete. McAfee and McMillan (1987, p. 700) suppose that auctions be studied as "explicit model of price making" and summarize the impact of von Hayek (1945): "To paraphrase Hayek in modern terms, the constraints imposed by informational asymmetries can be as significant as any resource constraints."

Not only is price dispersion a theoretical result, it is also an empirically observed phenomenon. That the "law of one price" cannot be supported empirically was already pointed out by Stigler (1961) and documented by Pratt et al. (1979). Herrmann-Pillath (2001, p. 45), for instance, argues within equilibrium theory that the "law of one price" "can be refuted unless the conditions of perfect general equilibrium are fulfilled." This means that in reality, there is no reason for the "law of one price" to hold because there will always be assumptions which are not met.

Refraining from the "law of one price" has several reasons. Theoretical models that deal with asymmetric information show that non-degenerate price distributions can be a stable equilibrium outcome. Empirical analyses emphasize and corroborate the theoretical findings. Firms are interested in consumers' search behaviour because they intend, for instance, to learn about the effects of price advertisement or pricing policy, i. e. whether there is a (price) strategy to attract new customers. Urbany et al. (1996) show that consumers search for prices. The extent of search depends on several factors which have not yet been fully understood (particularly those of psychological nature).[23]

Price dispersion has two non-exclusive reasons. First, consumers may search because the product is offered at various prices in different stores. The question remains where these differences come from. The other possibility is that firms charge different prices because they expect that not all consumers search for the lowest price. In theory, price dispersion for homogeneous goods is caused by the assumption of incompletely informed consumers. It is sometimes argued that there are hardly any homogeneous products in reality. If, however, there is a price dispersion for homogeneous goods that theory can explain, this is even true for heterogenous goods. Moreover, a consumer may prefer a certain supplier so that his price sensitivity is somewhat distorted. The natural consequence is that a certain product, such as Levi's 501 are sold at different prices. However, the assumption that the consumers do not have perfect information is quite realistic and can be accepted as

[23]Some papers that deal with consumer search from a marketing viewpoint are, for instance, Lynch Jr. and Ariely (2000) who analyse an online retail market for wine. Noble and Gruca (1999) and Cressman Jr. (1999) focus on industrial pricing. Urbany and Dickson (1988) take an empirical look at how different levels of consumers' information affect seller pricing. Bettman (1979) shows that restrictions on marketing policies are imposed by the constrained ability of consumers to remember information, i. e. how information should be provided.

the main cause of price dispersion. Several applications of the search cost approach are outlined in Chapter 2.[24]

In the following subsections, properties of the search theoretical models, which are of concern here, are summarized and some further advantages compared to the models that assume perfect information are outlined. In Section 1.4 it will be argued why the evolutionary approach of NELSON and WINTER (1982) can be improved by implementing a market mechanism influenced by search costs of the consumers.

Additional to the evidence that the search cost approach fits well to empirical data,[25] a general justification for applying search cost models may be that "search is one of the mechanisms for acquiring price information and ... price formation is the central issue of economic inquiry" (LIPPMAN and MCCALL (1993, p. 226)). According to LIPPMAN and MCCALL (1993, p. 239), the importance of search cost theory is reflected in the considerations that

> "the presence of imperfect and costly information gives rise to market power and nullifies the traditional theory of perfect competition. For example, the law of one price fails to hold in Stigler's model, in which the luck of the draw determines the buyer's price. In this work, however, it fails in the stronger sense that lack of buyer homogeneity can result in market failure or equilibrium with different customer classes paying different (expected) prices even if there are many buyers and sellers and many of the buyers are well-informed. Furthermore, product markets with a small number of firms can be more competitive than markets with a large number of sellers. Finally, the theorist must add imperfect information to his list of imperfections which can lead to price rigidities. These facts substantiate Stiglitz's view that in many instances the traditional competitive theory is fundamentally incorrect and misleading and, more importantly, that informational considerations are in fact fundamental to economic theory."

In the common neoclassical equilibrium model it is assumed that all economic agents only have to know the market price to be able to adjust their behaviour so that the equilibrium is reached (the "invisible hand"). Furthermore, the consumers are assumed to have perfect knowledge of all relevant factors, such as the prices of all

[24] That the search theory is a fruitful approach for many economic applications, is emphasized in the November 1999 issue of the International Economic Review. See e. g. the introduction by WRIGHT (1999).

[25] See e. g. BONTEMPS et al. (1999, 2000) and VAN DEN BERG and RIDDER (1998).

suppliers (to make sure that all suppliers offer the same price), the location of the suppliers, and the possibilities of reaching it at a minimum (or, usually zero) cost. In contrast to these indirect informational assumptions, the need for information in a search theoretic model is less demanding. Instead of assuming that consumers have complete information, it is sufficient to assume that the consumers know the price distribution.[26] Additionally, firms know the consumers' reservation price.[27] Instead of an aggregate demand function there are individual consumers behaving in a specified way and reacting to changing market conditions. Not only are firms simply price takers (adjusting their quantities), but they are aware of their (local) monopoly power. Although there are suppliers that are not matched to consumers, and there is a non-degenerate price distribution in equilibrium, the market outcome is generated by economic agents behaving in an optimal way. The price distribution is determined endogenously and the firms take into account the search strategies of the consumers. A price dispersion may exist even if all consumers as well as all firms are a priori identical.

Concerning the controversial assumption that all economic agents behave in a rational way, some experimental results are of interest. The behaviour observed in a price search experiment fits the theoretical predictions of rational behaviour quite well. This is demonstrated in several experimental studies by Rapoport and Tversky (1970) and Hey (1981, 1982, 1987, 1991). Rapoport and Tversky (1970) report that their subjects in an optional stopping task solved most of the exercises in an optimal way using a sequential search strategy, i. e. the observed behaviour tends to be consistent with the predictions of the theory.

Hey (1981) develops a theoretical framework to analyse optimal rules of search as well as reasonable rules of thumb in a complex environment. In Hey (1982), he presents first experimental evidence. In an experiment, where the participants had to search sequentially without information about the price distribution,[28] different search strategies can be extracted from the data. In the uncertain environment, most of the students used rules of thumb, which turned out to be quite good and

[26] This assumption is also abandoned in some of the models following Rothschild (1974).

[27] The reservation price is the maximum amount of money a consumer is willing to pay for one unit of the good.

[28] In this case, searchers are able to remember all observed prices.

robust. Conducting a further experimental study, Hey (1987) found out that his results depend on the amount of information that the searchers had been made available. He confirms his hypothesis that the search behaviour comes closer to the optimal rule when the amount of information increases. When the amount of information decreases, the participants used rules of thumb more frequently. The results correspond to Hey (1982), where about 40% used a 'reservation' rule (stop if the price is sufficiently low) and about 30% followed the 'optimal reservation' rule (stop if the observed price is lower than one's reservation price). The more information about the price distribution was given to the searchers, the more frequently the reservation rule was used. Hey (1991, p. 106) concludes that "in 71 per cent of all cases behavior was consistent with the use of some reservation rule — so although one should conclude that subjects' behavior departed from that prescribed by the optimality theory, it appears that subjects were *trying* to do the right thing." The decision process of individuals who do not behave in an optimal way is further investigated in Carbone and Hey (2001).

The existence of search frictions may even enhance efficiency. This is demonstrated by Acemoglu and Shimer (2000) in a general equilibrium framework with fixed-sample-size search. If consumers search, the monopoly power of firms decreases. This causes the prices to decrease and, therefore, to increase consumers' welfare. Acemoglu and Shimer (2000, p. 585) argue that "[b]ecause search is desirable, violations of the 'law of one price' may improve the allocation of resources." Knowing merely one price, no consumer would have an incentive to search. This would lead to the result of Diamond (1971) that all firms charge the monopoly price.

However, there are some shortcomings of the search cost approach. The most severe shortcoming is an inconsistency in firm behaviour. Firms do not behave in an optimal way, i. e. profit maximizing because they do not bargain with consumers who are unwilling to pay the offered price. This is not sub-game perfect since a firm would make positive profits if it sold the good at a lower price to such a consumer as long as its first price was above its marginal costs. This problem has been recognized for long, and different approaches have been formulated to deal with it. Jovanovic (1984, p. 111) argues that disadvantages arise for the firms if they sell their product at different prices (e. g. they lose reputation because they do not treat their customers equally). McMillan and Rothschild (1994, p. 916), however, propose to investigate further the effects of bargaining, as studied for example by WOLINSKY (1983). On the contrary, LIPPMAN and MCCALL (1993, p. 240) state that "the informational problems of bargaining and reputation usually do not lie in the search arena." In reality, we often find fixed prices at a shop (usually if it is too large to be served by the owner). Furthermore, this shortcoming seems to be negligible compared to the assumption of orthodox theory that firms do not recognize the world around them (perfect competition) or make permanently errors (Cournot conjecture in oligopolistic competition).[29]

The search theoretic approach also offers new insights into economic policy issues. Depending on how the search frictions work, it may be worthwhile to increase the consumers' base of knowledge to have positive impacts on the market structure or economic welfare in general. For the antitrust policy, a trade-off may arise between welfare losses caused by incomplete information or induced by monopolistic and oligopolistic market structures. Concerning taxation, one might argue that if studies show that search frictions increase the local monopoly power of firms, then it would be a good distributional instrument to impose (higher) taxes on profits for a leftist government.[30]

1.4 Combination of the Two Approaches

A broadly discussed issue in economics concerns the connection between innovation and market structure. Since empirically, product innovations are more important in their influence on market structure than process innovations, it seems to be somewhat unsatisfactory that NELSON and WINTER (1982) focus on process innovations. They argue, however, that it hardly makes any difference if their process innovations are interpreted as product innovations. To evaluate the success of innovations

[29] In Germany, for instance, the assumption that it is impossible for consumers to bargain over the prices is quite a realistic assumption, since the "Rabattgesetz" so far did not allow firms to reduce product prices substantially. Now that the "Rabattgesetz" is repealed, the behaviour of firms and consumers does not seem to have changed fundamentally, so that bargaining is still of minor interest.

[30] WILDE and SCHWARTZ (1979) show how a search cost approach can substantiate a legal debate on the disclosure of information to consumers. They analyse the impact of a reduction of search costs on the establishment of a competitive equilibrium.

it is necessary to know how the demand side works. The studies mentioned above "neglect" the consumers; they simply assume that there is a (unit elastic) aggregate demand function. Furthermore, firms sell their goods for the same market clearing price.[31]

On the contrary, there are models that connect consumers and producers in a more realistic way than the price search models, but only very few of them deal with innovations. If cost shocks are interpreted as innovations, FISHMAN (1996) can be regarded as preliminary work to this thesis. In his model, however, cost shocks are considered exogenous. It is not explained where the incentives to change behaviour result from, i. e. the changes of cost that lead to an adjustment of supply.

There has been a considerable amount of research into the understanding of the innovation process. Schumpeter is often cited as pioneer, but he never set up a formal model.[32] Analytical approaches can often be found in the industrial organization literature, but they do not meet the demands of the evolutionary economics approach. Some evolutionary simulation studies have been discussed above, but none of them considers the demand side. Most of the papers concerning price distributions "only" deal with the establishment of steady states. One approach that covers some of the dynamics involved by an adjustment process of firms to macroeconomic shocks is developed by FISHMAN and ROB (1995), who make the first attempt to interpret a search-theoretic model towards evolutionary theory. This model, however, is still based on the concept that the economy converges to a static equilibrium.[33] Nevertheless, it seems possible to interpret the positive cost shocks as successful innovations securing profitability for some periods. To remain powerful a firm has to strengthen its position because competitors also innovate and, after a while, a firm will be driven out of the market if its technology is no longer competitive. This means that the cost shocks are not totally random because they depend on R&D efforts of the firms. Additionally, small (and medium sized) enterprises can survive

[31] LINK (1997), for instance, shows that the adoption and the diffusion of innovations strongly depend on the consumers' willingness to pay.

[32] See e. g. DINOPOULOS (1996).

[33] If instead of infinitively lived consumers it is assumed that new consumers enter the market and old ones exit, this flaw could possibly be avoided although in this model it may lead to a unique steady-state equilibrium as argued by FISHMAN and ROB (1995, footnote 10, pp. 33).

in such a market and co-exist with large firms. Unfortunately, Fishman and Rob (1995) do not explain where the cost shocks come from.

Another approach is provided by Bontemps et al. (2000). They assume identical consumers, but firms differ with respect to their production costs. A very interesting feature of their model is that the consumers are divided into two groups: those who search for the first time and those who have already found a supplier. Moreover, the consumers who have already found a supplier do not stop searching but look for better opportunities. As firms are being likely to go bankrupt, there is a steady flow of consumers into and out of the market. The equilibrium concept applied is one of a demographic steady state, i. e. an equilibrium in consumer flows. Although the model has some dynamic features, Bontemps et al. (2000) do not explain either where the differences in costs originate.

The combination of search cost theory with the evolutionary simulation model of Winter (1984) closes this gap and offers an explanation for the heterogeneity of firms. Therefore, for the hybrid model presented in this thesis, the approach of Bontemps et al. (2000) is implemented into the framework of the Winter (1984) model. It will be shown that the hybrid model is able to reproduce stylized facts of innovative industries in particular. Further, simulation results show that it is worthwhile making a distinction between the two groups of consumers because they have varying effects on the development of the industry.

The aim of this thesis is to combine the advantages of both strands of literature and answer, for instance, the following questions. How does the market structure develop if the amount of consumers' information varies? What is the impact of the informational structure of the demand side on variables, such as the intensity of innovation, the number and size of firms in the market, or the price distribution? May a tendency to concentrate be thwarted by consumers' search activity? Are there any trade-offs between consumers' welfare and economic change?

It is possible and useful for several reasons to combine an evolutionary simulation model and a search theoretic equilibrium model. Evolutionary simulation models are usually characterized by state variables in each period. Transition rules cause the change in the variables' values. These rules determine how the variables change from one state to the next, given the values of the current period and of former periods. As the next state depends on all former realizations of states and there is uncertainty (mainly due to the stochastic innovation process), the transition is characterized by a Markov process. Thus, the economic variables evolve without employing any short-run or long-run equilibrium concept. There is, however, one exception: As for modelling the interactions between the supply side and the demand side to determine the market outcome (i. e. at which price the produced quantities are sold), it is simply assumed that the demand side is represented by a unit-elastic demand function and that the firms can sell the whole quantity they produce. There is only one market-clearing price, which is determined by the quantity supplied and the aggregate demand curve.

Some of the advantages of the search cost approach compared to this market equilibrium have already been mentioned. What is even more remarkable is that the latter is used in an evolutionary model which is to explain the process of innovation. In a market where innovations can be observed, the firms must have (the prospect of) positive profits to cover their expenditures on R&D. If they are able to make positive profits, it does not make sense to assume perfect competition where a single firm does not have any influence on the market price and acts as a price taker. Instead, firms must have some (local) monopoly power and the possibility of making their investment in R&D profitable. Therefore, the concept of perfect competition where the firms face an aggregate demand function seems to be inappropriate. If it is accepted that the firms exhibit some monopoly power, an equilibrium concept has to be implemented which allows for different prices depending on the characteristics of the firms. The most prominent and promising approach seems to be a model of price search where the firms are able to exploit consumers up to a certain extent. Additionally, the amount of empirical evidence given for the existence of significant price dispersion is overwhelming.

Both models, the evolutionary simulation model and the search theoretic approach chosen for this study, have in common that they assume a market for a homogenous good. As for the consumers, it is assumed in both models that they maximize their expected utility. In the evolutionary model, the firms are no profit maximizers. They try to survive by developing competitive technologies. Depending on the success of their behaviour compared to that of other firms, they have to exit the market if their performance is relatively bad. A good strategy is to increase the market share since this is the base for high profits.

The most important extension concerning the implementation of the search cost model is that the interactions that take place in the market between firms and consumers are explicitly taken into consideration. Firms cannot only be successful by using good technologies. They also have to find out how to acquire and keep customers to sell their products. The strategy of a firm depends both on the strategies of all other firms and on the consumers' behaviour. In turn, consumers react to the offers that are made by the firms. Thus, there is feedback from consumers to suppliers and vice versa.

To elucidate the idea of models concerning consumers' search, some pioneering approaches are pointed out in Chapter 2. The search model of Bontemps et al. (2000), that constitutes an important part of the hybrid model, is described in Section 2.3. The combination of the evolutionary approach of Winter (1984) and the search model of Bontemps et al. (2000) is presented in Chapter 3. The way of performing the simulation and its results are shown in Chapter 4.

Ignorance is like subzero weather: by a sufficient expenditure its effects upon people can be kept within tolerable or even comfortable bounds, but it would be wholly uneconomic entirely to eliminate all its effects. And, just as an analysis of man's shelter and apparel would be somewhat incomplete if cold weather is ignored, so also our understanding of economic life will be incomplete if we do not systematically take account of the cold winds of ignorance.

STIGLER (1961, p. 224)

Chapter 2

The Search for the Lowest Price

2.1 Introduction

The observation of STIGLER (1961, p. 213) that price "dispersion is ubiquitous even for homogeneous goods" lays the foundations of the research on "one important problem of information — the ascertainment of market price." He considers a wide range of aspects and perspectives concerning this subject, such as the search for profitable investments, job search, search for locations, and possibilities of reducing search costs. In this chapter, the development of the price search literature is traced from the beginnings till the latest developments.[1] Whereas the first studies show that a non-degenerate price distribution can be an equilibrium outcome indeed, attention is then focused on minimum requirements to achieve such an equilibrium.[2]

[1] The starting point is STIGLER (1961). LIPPMAN and MCCALL (1993) review some potential predecessors such as Hicks, Knight, Schumpeter, and Alchian, who are not further considered here. HEY (1981, p. 48) remarks that Herbert Simon was the first to present a model of a sequential search strategy in 1955.

[2] The most recent surveys are LIPPMAN and MCCALL (1993) and MCMILLAN and ROTHSCHILD (1994). Although search cost models have been making their arrival in textbooks, e. g. NICHOLSON (1995), they are still far away from being implemented thoroughly. Further surveys are provided by LIPPMAN and MCCALL (1976a,b), and STIGLITZ (1989). A special issue of the *International Economic Review* containing contributions, for instance, by BONTEMPS et al. (1999), FISHMAN

In order to give an impression of the variety of empirical applications that have been performed, some papers are exemplified (clearly, the list is far from complete). The Marseille wholesale fish market, for instance, is studied by KIRMAN and VRIEND (2000) and WEISBUCH et al. (1997). SORENSEN (2000) gives political advice concerning retail markets for prescription drugs. Data of the U. S. cement industry are analysed by ABBOTT III (1994). MINKLER (1992) offers an explanation for why firms like Coca-Cola franchise. The pioneers, PRATT et al. (1979), study 39 products ranging from air conditioners to vocal instructions. Regarding the labor market, there are numerous studies. Examples that are related to the model of BONTEMPS et al. (2000) are BOWLUS et al. (2001), which is an application of BURDETT and MORTENSEN (1998) in transitions from school to work, and KONING et al. (2000) who make a distinction between the effects of search costs and minimum wages on unemployment. Empirical and policy implications are summarized by LIPPMAN and MCCALL (1976b). Equally, the search cost models are of growing interest in the marketing literature. LYNCH JR. and ARIELY (2000) analyse electronic shopping for wine, and NOBLE and GRUCA (1999) focus on industrial pricing to give managers some advice in pricing strategies. URBANY and DICKSON (1988) perform an experiment on how information influences dispersion in the retail grocery market, and URBANY et al. (1996) emphasize the importance of habitual and psychological effects using again data of the retail grocery market.

This chapter is organized as follows. Section 2.1 summarizes properties of search mechanisms. In Section 2.2, the basic structure of the search models is explained and an overview of the respective literature is given. The chapter concludes with a detailed description of BONTEMPS et al. (2000) which is an extension of the approach of MORTENSEN and NEUMANN (1988). The labor market model is adjusted to fit the notion of a consumer market with price search. This model is described in detail because it will be used as a central part for modelling the market process in an evolutionary framework in Chapter 3.

Equilibria with price dispersion on a market for a homogeneous good can be viewed as generalizations of the concept of market equilibrium under perfect information. Not until the first formalization of consumers' search was made by STIGLER (1961),

and ROB (1999), MORTENSEN (1999) and ACEMOGLU and SHIMER (1999) on the topic of search and matching is introduced by WRIGHT (1999).

was a state of a market with more than one price viewed as an equilibrium. Before, it had been regarded as a state of transition from one (single-price) equilibrium to another. Therefore, one of the merits of STIGLER (1961) is that he provides a method of achieving a steady state of a market with a non-degenerate distribution of prices.

Obtaining information is almost always costly for the agents. As is shown later, the existence of search costs is the main reason for sustaining a multiple-price equilibrium. If search costs tend to zero, all prices are usually forced down to the competitive marginal cost price. If search costs are extremely high, the prices will tend to the monopoly price.[3] To sum up, one result of the search theoretic models is that the local monopoly power of the firms decreases as consumers obtain more information.[4]

For a market in which buyers are assumed to search for a low price, STIGLER (1961) mentions that search costs can mainly be ascribed to the time needed for obtaining the desired information. He suggests regarding search costs as approximately proportional to the number of sellers visited and assuming constant marginal costs. This argument of STIGLER (1961) is surely valid for certain markets. One can, however, imagine that cost of transportation or communication also play an important role in some other markets. Furthermore, there can be network or scale effects of searching. Reducing the search costs for consumers may be achieved by pooling information among groups of buyers, word-of-mouth publicity, specialised traders (intermediaries), or allowing the firms to advertise product prices and thus being identified without search. STIGLER (1961) maintains that price advertising reduces the dispersion of prices, which, however, does not vanish completely because not all of the buyers are reached by the advertisements.[5]

A crucial assumption in the search-theoretic models is the homogeneity of the good searched for. STIGLER (1961, p. 214) interprets price dispersion on a market for

[3] The shape of the distribution depends crucially on the assumptions since an equilibrium where two prices are observed simultaneously has a non-degenerate price dispersion.

[4] ANDERSON and RENAULT (2000) show that the converse also may be true. In their model, prices increase as the proportion of informed consumers increases. This, however, is due to some specific assumptions.

[5] See e.g. BUTTERS (1977).

homogeneous goods as a measure of ignorance,[6] although this measure is biased if it is assumed that "there is never absolute homogeneity in the commodity if we include the terms of sale within the concept of the commodity". His examples of a market for used cars (Chevrolets) demonstrates how loosely the term "homogeneous" is used. To avoid any critique, some empirical studies differentiate the goods so rigorously that "homogeneous" seems to be appropriate indeed.[7]

Beyond product heterogeneity, some other reasons for price dispersions have been proposed, such as a priori heterogeneity of buyers or sellers, and search costs of firms of their rivals' prices. It has been proved for all of these reasons that they are not essential for obtaining a price dispersion in equilibrium. The only necessary condition for price dispersion is the existence of positive consumers' search costs.[8] They affect the informational structure in such a way that ex ante identical consumers become ex post heterogeneous. The result of the search process is stochastic, i. e. after searching, the consumers exhibit different states of knowledge.

To corroborate the theoretical considerations with respect to the impact of product heterogeneity on price dispersion with empirical evidence, ABBOTT III (1994) tests three hypotheses with data from the U. S. hydraulic cement industry, employing a production function framework.

The first hypothesis, that the observed price dispersion is caused by product heterogeneity, is rejected. Neither transportation nor transaction costs are able to explain the phenomenon of price dispersion. The second hypothesis tested is whether the observed price dispersion is the result of aggregating data across several regional markets. This assumes that there are different prices for the same product because

[6]According to TOMMASI (1993) one should be careful with this interpretation, particularly in empirical studies. He argues that on the one hand ignorance, i. e. when consumers do not acquire much information, may lead to a higher average price, but on the other hand it is not clear how a higher average price affects the distribution of prices. TOMMASI (1993) shows that an increased average price also can lead to an increase in the variance of the price distribution. These findings are opposed to the intuition of STIGLER (1961).

[7]ABBOTT III (1994), for instance, uses data of products that have to fulfil strong standards such as special kinds of cement, see below.

[8]Though being a necessary condition, the assumption of positive search costs is not sufficient, as will be outlined in Section 2.2. A general proof of the existence of non-degenerate price distributions in a sequential search model is given by BERNINGHAUS (1984).

the relevant market is not accurately defined. The second hypothesis is also rejected although some regional components can be detected in the prices.[9] But Abbott III (1994) leaves no doubt that the observed differences in prices for the U. S. hydraulic cement industry can neither be put down to product heterogeneity nor to aggregation errors. The last hypothesis is based on this knowledge. Since the second hypothesis is a question of how to define the "right" market and, additionally, evidence against competitiveness of the industry has been found, the third hypothesis is whether firms have local market power. It is assumed that firms are characterized by downward sloping demand curves and adjust the product prices to local cost and demand changes. Abbott III (1994) finds considerable evidence for the local market power hypothesis, but he is not able to explain the source of price dispersion completely. His empirical findings imply that the search cost approach may be an explanation of how firms achieve or maintain market power. These results are in line with the first systematic empirical investigation by Pratt et al. (1979), who find considerable differences in prices for homogeneous consumer goods in the Boston area. They also discover that the variability of prices is lower for goods that are purchased more frequently.

The empirical findings support the theoretical analysis: equilibria, which are characterized by a non-degenerate distribution of prices may be stable market outcomes, i. e. steady states. One reason why price distributions do not vanish over the course of time is that they are supported by changing market conditions. This can be achieved, for instance, by introducing a flow of new, ignorant buyers in each period, so that knowledge becomes outdated.

Even for a priori homogeneous agents,[10] the price of a homogeneous good can vary between different sellers. Consumers who intend to buy from a seller offering a low price have to ascertain the prices. In searching for prices, several strategies (search mechanisms) can be applied to determine the amount of (costly) information so as to maximize a consumer's surplus. Some categories of search mechanisms are:[11]

[9] A model of spatial competition is analysed by Miller (1996).

[10] "Homogeneous agents" stands for homogeneous consumers and homogeneous suppliers.

[11] For a detailed discussion of the properties of the search mechanisms, see e. g. McAfee and McMillan (1988), Morgan and Manning (1985), Manning and Morgan (1982), and below.

- Fixed-sample-size search: There is only one period. Before starting to search, the consumer has to decide how many price quotations he[12] desires to obtain. He calculates the optimal number of search steps in the beginning so that the expected marginal gain from searching equals its marginal costs. At the end of the period he will decide whether to buy from the cheapest seller or to exit the market without purchasing anything. As all the information is received in one period, it is also referred to as non-sequential search.

- Sequential search: There are several subsequent periods in which a consumer wishes to buy a product (repeated purchase). In each period, a consumer can visit one seller to receive one price announcement. After each step he decides whether to buy at the shop he has just visited or to continue searching. At the beginning of every period he calculates whether the expected gain from an additional search exceeds its costs. In a stable world, these calculations result in a reservation price leading to the policy "Buy if the observed price is less than or equal to the reservation price, and continue search otherwise."

- Noisy search: This mechanism can be applied to sequential as well as non-sequential search. There is a positive probability of observing more price quotations at a time than the consumer has paid for. A fixed-sample-size searcher, for instance, additionally receives advertisements, or a sequential searcher receives a number of price offers drawn from a probability distribution.

- Search with/without recall: This differentiation is only of interest for sequential search. A consumer searches with recall if he can remember the prices of previously visited sellers so that he can purchase at one of the so far visited sellers. If he is constrained to decide from seller to seller whether to buy immediately at the currently visited seller, or to visit another seller, or to stop searching, he is searching without recall.

- Combination: Strategies combining features of sequential and non-sequential search mechanisms, for instance, a fixed-sample-size searcher can decide in more than one period on the size of his sample.

[12]It is only the masculine form that is referred to in this thesis in order to facilitate reading.

So far, different possibilities have been outlined without concerning their properties. To decide whether a search mechanism is superior to another, the main assumptions and their consequences have to be analysed with respect to optimality.

Optimality of search mechanisms is an item discussed controversially. Built on a simple model, the approach of Rothschild (1974) shows that sequential search is superior to fixed-sample-size search because the former leads to higher gains from search for the consumers.[13]

A consumer will be better off if he received more than one offer per period. Manning and Morgan (1982) argue that additionally to the question whether the rule is applied in an optimal way once it is chosen, it should be analysed whether the rule itself is optimal. This depends on several parameters, such as the cost structure of search, possible delay costs, and generally on the search task to perform, which has also been pointed out by Wilde and Schwartz (1979). The search for an optimal strategy is extended by Morgan and Manning (1985). They argue that sequential and fixed-sample-size search have advantages and, consequently, they develop a mechanism that includes both strategies as special cases. A comparison of properties concerning search with and without recall can be found in Morgan (1983).

Further elaborations are contributed by McAfee (1995), who extends consumers' activities to multi-product search, and Gatti (1999) who proves the existence of a reservation price rule with multi-product search. McAfee and McMillan (1988), Myerson and Satterthwaite (1983), and Peters and Severinov (1997) compare auctions with search mechanisms taking into account total gains from trade instead of only consumers' surplus. Talmain (1992) analyses optimality assuming that price distributions are unknown. For an inter-temporal allocation, the properties of search strategies are shown by Manning and Manning (1997).

Another criterion for selecting a search mechanism is provided by experimental studies, such as Hey (1982) and Houser and Winter (2001). They indicate that sequential search is a good approximation of rational behaviour. Seale and Rapoport (1997) report that their experiments show that in solving a sequential

[13] That an optimal decision rule exists under the assumption of sequential search is proven, for instance, by Lippman and McCall (1976a) and Kohn and Shavell (1974).

search problem with finite opportunities, simple heuristics have proven to be nearly as good as the optimal strategy.

2.2 Price Search Models: A Survey

In this section, three types of search models are discussed. They are divided with respect to their aims, i. e. to establish an equilibrium under minimal assumptions, to give empirical evidence, and recent extensions. The section begins with a description of the basic structure and idea behind the search theoretic models.

As a starting point, the model of STIGLER (1961) with non-sequentially searching consumers is chosen. It is followed by the critique of ROTHSCHILD (1973). The model of DIAMOND (1971) and the related model of REINGANUM (1979) are discussed to clarify the most important components and ideas of a search model. In these four pioneering papers, the fundamental concepts of search models are developed. Afterwards, some papers concerning necessary conditions for price dispersed market equilibria are pointed out. The last part of this section gives an overview on recent research. In Section 2.3, the work by BONTEMPS et al. (2000) is presented, which constitutes one of the standing legs of the simulation model presented in Chapter 3.

The basic structure of the models analysing dispersed price equilibria can be outlined as follows. Consumers intend to buy one or more units of a good at the lowest price. On the supply side, sellers are assumed to quote different prices.[14] Since consumers are assumed to know only the distribution of prices without knowing the locations of the sellers, they have to search at least once, i. e. they have to identify a seller. For each announcement a consumer wishes to receive, he has to pay a fixed and constant amount of money, the search costs c. These search costs prevent consumers from becoming perfectly informed because there is usually a turning point from which on the cost of search are not further outweighed by the

[14] The assumption that the sellers fix the prices does not describe any constraint for the model. WOLINSKY (1983) shows that if consumers are able to bargain prices down, the magnitude and variability of prices depend on consumers' search costs in the usual way. For more on bargaining theory in this context, see e. g. the survey by MCMILLAN and ROTHSCHILD (1994, pp. 916).

gain from search.[15] Depending on the preferences of the buyers and the standard deviation of the price distribution, it can be beneficial to search more than once, even if he has to pay for the information. This is because he can find a lower price and, additionally, increased search activity is expected to result in a decrease of the minimum asking price of the sellers. In equilibrium the expected savings from search per unit demanded equal the expected reduction in price induced by search, where the savings are higher with a greater standard deviation of the price distribution and higher expenditures for the product. The models of price search can be distinguished with respect to the source of price dispersion (supply or demand side), heterogeneity of agents, knowledge of the price distribution, search mechanisms, static or dynamic approaches.[16]

PART I. In the non-sequential search model of STIGLER (1961) it is assumed that the prices p are distributed according to a cumulative distribution function $F_P(p)$ which is known to the consumers.[17] A consumer has to decide how many prices he wishes to ask for before he starts searching. If he searches only once, his expected price to pay would be[18]

$$E(p) = \int_0^\infty [1 - F_P(p)]dp.$$

If he decides to search $n > 1$ times, he will observe n prices $p_j, j = 1, \ldots, n$. As he will buy from the seller with the lowest observed price, the expected price he will pay is just the expected value of the minimum of the n observed prices from the known distribution $F_P(p)$. Let $m := \min\{p_1, \ldots, p_n\}$ be the minimum of the observed prices after n searches. Then the distribution of the minimum price after n searches is defined as

$$F_M(m(n)) = \text{prob}(m(n) \leq p) = 1 - [1 - F_P(p)]^n,$$

[15] If it is assumed that the consumer does not increase his utility by shopping around, his gain will be the reduction in price obtained by further search.

[16] A slightly different categorization together with several references is provided in MCMILLAN and ROTHSCHILD (1994, p. 912).

[17] Although STIGLER (1961) illustrates his expositions with uniformly distributed prices his ideas are shown in a general way.

[18] The expected value of a random variable P is defined as $E(p) = \int_0^\infty [1 - F_P(p)]dp - \int_{-\infty}^0 [1 - F_P(p)]dp$, but since prices are always positive, the second integral vanishes, see e. g. MOOD et al. (1974, p. 65).

and the expected minimum price after n searches is

$$E(m(n)) = \int_0^\infty [1 - F_M(m)]^n dm.$$

The expected price a consumer will pay decreases as the intensity of search, n, increases. The expected gain from an additional search (in terms of reduction of the price) can be written as

$$G(n) = E(m(n)) - E(m(n+1)) = \int_0^\infty [1 - F_M(m)]^n F_M(m) dm.$$

The expected gain from an additional search decreases as n increases, but it always remains positive.

If it is assumed that obtaining information on prices is costly, then, with constant search costs c per observation, the consumer chooses the optimal number of observations, n^*, so that it satisfies the condition

$$G(n^*) \geq c > G(n^* + 1),$$

that is, n is chosen so that at n^* the cost of an additional search, c, is less than or equal to the expected benefit of an additional search.

Therefore, n^* is the solution to the consumers' problem

$$\min E(m(n)) + c \cdot n.$$

Although Stigler's model is very clear in general, it has several weak points. ROTHSCHILD (1973) criticises that the consumers' decision rule is not optimal. With the assumptions made above, sequential search would make a consumer better off because he can decide step by step if further search is beneficial.

If sequential search is assumed in this framework, the optimal policy for a consumer has the reservation price property. There is a certain critical price, the reservation price, so that any offer with a price below the reservation price will be accepted and any offer above it will be rejected. The reservation price R results from the calculation that the cost of obtaining an additional price offer, c, has to equal the expected benefit of that additional price offer. Then, R is defined as solution to the equation

$$G(R) = c \quad \text{with} \quad G(R) = \int_0^R F_P(p)dp.$$

A consumer who has high search costs has a higher reservation price than a consumer who has low search costs. The optimal sequential search policy[19] is to accept an offer p if $p \leq R$ and to reject it if $p > R$. Let m_t be the minimum observed price after t periods if exactly one price per period is observed. Then, the expected gain from an additional search equals

$$G(m_t) = \int_0^\infty (m_t - p)dF_P(p) = \int_0^{m_t} F_P(p)dp$$

and search stops after period t if $c > G(m_{t+1})$.

A second critic of Stigler's model refers to the supply side. ROTHSCHILD (1973, p. 1288) calls the model a "partial partial-equilibrium theory" because the origin of the different prices is not explained. He draws the conclusion that if the price-setting agents are not specified, they cannot be influenced in price setting by the consumers' decisions.

In his seminal paper, DIAMOND (1971) complains about the equilibrium theory not being able to explain several observed economic phenomena and the developing field of disequilibrium economics concentrating mainly on adjustment processes to competitive equilibria. Therefore, the economic agents in his model are able to adjust to changes, and prices are set explicitly by sellers instead of the Walrasian auctioneer.

In his model, there are many identical firms and many consumers. In each period, a firm determines the product price. A consumer visits one firm per period and either buys according to a demand function[20] and exits the market or leaves the store if the price is above his reservation price, revises his reservation price and searches again

[19]For the *existence* of search policies, see BERNINGHAUS (1984) and LIPPMAN and MCCALL (1976a, pp. 161).

[20]Then, "the different quantities might represent quality or size differences, as e. g., the dimensions of a television picture" (DIAMOND (1971, p. 157)).

in the next period. Firms may charge different prices, and all firms including those currently visited can adjust the product prices in the next period. Firms know the demand functions and the reservation prices of the consumers and maximize their profits each period, making use of their knowledge about consumers' reservation prices. Given the buyers' and sellers' behaviour within a period, the transition between periods is determined by an adjustment both of reservation prices and the number of consumers: "lucky" consumers leave the market, "unlucky" ones revise their reservation prices, and new consumers enter the market.

The main result of the paper is that the price distribution vanishes, but the resulting market price does not converge to the competitive equilibrium price. Instead, the market price adjusts in finite time to the joint profit maximizing price, i. e. the monopoly price. In this model, price dispersions are only considered as a phenomenon occurring during the adjustment process to a long-run equilibrium characterized by a single price. They are not recognized as stable outcomes of the described market process. This result does not change fundamentally if entry of new firms is taken into consideration. The equilibrium price decreases, but it still lies above the competitive marginal cost price.

Although — or perhaps because — Diamond's focus was to show that there are conditions under which an economy does not converge to a competitive equilibrium and only accepted price dispersion as an out-of-equilibrium phenomenon, his paper together with Stigler's inspired much further research on the topic of price dispersion. Plenty of empirical evidence shows that there are differences in prices for homogeneous goods remaining over long time periods. Therefore, most of the subsequent papers considered to refute the results of Diamond and demonstrate that also in a theoretical framework a non-degenerate price distribution can be a stable equilibrium outcome.

Another concern of the subsequent literature was to supplement Stigler's attempt to explain why firms charge different prices. Often cited advocates are, for instance, Butters (1977), Salop and Stiglitz (1977), and Reinganum (1979). They emphasized that only one of Diamond's assumptions has to be modified to avoid his result that only single-price equilibria exist.

They all depart from the "deadly 'simplest model' ", that Reinganum (1979, p. 852) characterizes by identical consumers, unitary demand, sequential search, fixed search cost, and identical firms. Further, they agree that "imperfect information *alone* is insufficient to support price dispersion" (Reinganum (1979, p. 852)). However, they differ in their choice which one of the assumptions of Diamond (1971) is modified to obtain price dispersion in equilibrium.[21]

In the model of Salop and Stiglitz (1977) consumers are characterized by unitary demand and heterogeneous search costs. There is one group of consumers with low and another group with high search costs. For a fixed search cost, a consumer can become perfectly informed about all prices. The identical firms behave as monopolistically competitive, and price differences among firms are caused by increasing marginal costs and U-shaped average cost curves. Cost differences occur because of different output levels generating different average costs. Their main statement is that positive search costs result in equilibrium prices above the competitive price. In contrast to Diamond (1971), additionally to the one-price equilibrium, a permanent price dispersion may also occur in equilibrium.

A one-price equilibrium is characterized by a price vector, the number of firms in the market (because free entry is assumed) and the proportion of searching consumers so that firms maximize profits, each firm has zero profits, and consumers search in an optimal way. The equilibrium price is either the competitive price (if search costs are zero or the proportion of searchers is high) or the reservation price. If a one-price equilibrium does not exist, there is either a two-price equilibrium or no equilibrium at all. If a two-price equilibrium exists,[22] it is defined by the price vector, firm number and proportion of low-price firms so that profits are maximized, the zero-profit condition holds and only consumers with low search costs become informed. Here, the minimum price equals the competitive price and the maximum price is the minimum either of the monopoly price or the price at which the high-cost consumers are indifferent between searching and purchasing randomly.

Reinganum (1979) deviates from the "simplest model" by assuming constant elasticity demand functions instead of a unitary demand and implementing different constant marginal costs for the firms. Apart from proving the existence of a non-

[21] A more recent approach is Fishman and Rob (1998) where the result of Diamond (1971) is avoided by introducing uncertainty about demand (see pp. 50).

[22] Varian (1978, p. 245) notes that "sufficient conditions for the existence ... are rather delicate; it turns out that existence depends critically on the global behavior of the average cost curve."

degenerate price distribution she shows that the persistence and degree of price dispersion in her model rely on both of the aforementioned assumptions.

There is a continuum of identical buyers who maximize the expected utility of their limited wealth, i. e. they search as long as the expected increase in utility from an additional search is positive. They search sequentially with recall for a low price in a market which is characterized by a known distribution of prices, $F_P(p)$.

In contrast to the models cited previously, the consumers buy in accordance with an elastic demand function. The expected gain from an additional search is no longer simply determined by the difference between the expected minimum price of the current and the subsequent period. To account for the effects that the quantity demanded depends on the price and that the value of search increases with the quantity demanded, the concept of an indirect utility function is implemented. The indirect utility function V is a function of the product price p, the given price of all other goods, p_0, and the consumers' wealth, W. It is given as $V = V(p_0, p) + W$. At given prices and income the indirect utility function measures the maximum utility that can be achieved. The price distribution is given by $F_P(p)$ where $F_P(\cdot)$ is continuously differentiable almost everywhere and has positive density $dF_P(p)$ on the closed interval $[\underline{p}, \bar{p}]$ for some p and $\bar{p} > \underline{p}$ in $\mathbb{R}^+$.

The expected gain in utility from searching once more is denoted by[23]

$$\begin{aligned} h(m_t) \;=\; & \textstyle\int_{\underline{p}}^{m_t} [V(p_0, p) + W - (n+1)c] dF_P(p) \\ & + \textstyle\int_{m_t}^{\bar{p}} [V(p_0, m_t) + W - (n+1)c] dF_P(p) \\ & -[V(p_0, m_t) + W - n \cdot c], \end{aligned} \tag{2.1}$$

when fixed sampling cost per observation is c and the lowest price of the first n searches is m_t. The first integral represents the expected gain in utility of an additional search if a lower price than m_t is observed. The second integral stands for the gain in utility if m_t is still the lowest price. Finally, the utility from paying m_t without searching further has to be subtracted. Equation (2.1) simplifies to

$$h(m_t) = \int_{\underline{p}}^{m_t} [V(p_0, p) - V(p_0, m_t)] dF_P(p) - c.$$

[23]Since an indirect utility function is used, costs have to be subtracted.

To ensure that each consumer searches at least once it is required that $h(\bar{p}) \geq 0$. If W and $V(p_0, \underline{p})$ are finite, an optimal stopping rule exists. The sequential search mechanism has the reservation price property, i. e. a unique reservation price R with $h(R) = 0$ exists.

Since all buyers are assumed to be identical, they face the same reservation price. The quantity demanded by one buyer is given by a constant elasticity demand function

$$D(p) = \begin{cases} q(p) & \text{for} \quad p \leq R, \\ 0 & \text{for} \quad p > R. \end{cases}$$

On the supply side, there is a continuum of firms with each firm j producing with constant marginal costs k_j. The sellers have perfect information and choose the price p_j that maximizes expected profits if N_j consumers sample firm j. A firm's expected profits are given by

$$E[\Pi_j] = \begin{cases} (p_j - k_j)q(p_j)E[N_j] & \text{for} \quad p_j \leq R, \\ 0 & \text{for} \quad p_j > R. \end{cases}$$

If a firm charges a price above R, no consumer will demand the good and, therefore, no profit-maximizing firm will offer a price above R. Further, there is no need to charge a marginal-cost price while firms have some monopoly power due to positive consumers' search costs.

A Nash equilibrium is defined by the buyers' reservation price, the distribution of prices, and the given price range. The resulting equilibrium has a non-degenerate distribution of prices. The prices are neither all at their minimum (marginal costs) because of the positive search costs nor are they all at their maximum (reservation price). This can be attributed to the property of the elastic demand function that at low prices higher quantities are bought than at high prices.

Weakening only one of the main assumptions would lead to different results. Therefore, the conclusion of Reinganum (1979, p. 857) is that cost differences as well as elastic demand functions "are essential to provide firms with an incentive to price below the reservation price". However, the consumers' search behaviour remains unexplained because in equilibrium only a single search is required. Strictly speaking, it is not a model of search because each consumer is matched randomly to a supplier. Reinganum (1979) suggests eliminating this shortcoming by assuming different search costs for the consumers.

Another way of showing that price dispersions exist is considered by Butters (1977). Assuming noisy search, Butters (1977) creates a two-stage model where identical firms can advertise so that the consumers, randomly and free of charge, become informed about none, one or even more firms. In the first stage, consumers can only buy at a firm from which they have received an advertisement. If the price offer is lower than their reservation price, they buy from the cheapest firm exactly one unit, otherwise they do not buy anything.[24] Search is introduced in the second stage. Each consumer is allowed to search for prices at costs $c(n)$, constant or increasing in n, regardless of having received advertisements. It is a limiting case of the first stage and produces results as expected: higher search and advertising costs lead to higher prices (buyers are willing to pay higher prices) and to larger price dispersions. Consumers only search if they do not receive an advertisement, and provided that they search they will search only once. In equilibrium all consumers buy one unit. The minimum price is above marginal costs if at least one consumer receives an advertisement. Interestingly, the price always increases if either advertising *or* search costs increase, and the dispersion of prices increases if advertising *and* search costs increase.

While in the price advertising model of Butters (1977) consumers' search is introduced in the second stage, Robert and Stahl II (1993) analyse this situation from the opposite. Starting from a sequential consumer search model built on the model of Diamond (1971), they show what effects additional information (e. g. supplied to the consumers as price advertisements) has on the endogenously determined price distribution. They show that prices decline if advertising costs shrink, and for zero advertising costs prices are competitive. Prices, however, remain above the competitive level even if search costs shrink.

A shortcoming of the models outlined so far is that consumers should know the price distribution while they do not have any idea of the location of the firms. Rothschild (1974) analyses the case where consumers sample from an unknown distribution of prices. He compares the properties of sequential search from a known

[24]Note that since firms have perfect information, the maximum selling price does not exceed the consumers' reservation price.

distribution with the properties of sequential search from an unknown distribution. Starting with the fixed-sample-size rule of Stigler (1961), the following properties of this search rule are summarized by Rothschild (1974, pp. 690).

1. If all potential customers follow this search rule, the demand function faced by a firm is well-behaved and the expected sales are non-increasing in the price.
2. Search behaviour depends on the search costs c and the price distribution $F_P(\cdot)$.
3. Increasing search costs lead to a decreasing search intensity and, thus, to a higher reservation price.
4. A larger variance in the price distribution leads to a lower expected price and, therefore, to lower expected total costs (the reservation price decreases).

As is shown by Rothschild (1973), the optimal search rule is sequential and has the reservation price property. It also has the four properties listed above. Additionally, the sequential search rule has the property that

5. a larger variance increases the search intensity,

which does not hold necessarily for the fixed-sample-size rule.

Under the assumption of sequential search without recall from an unknown distribution he shows that property 1 holds not necessarily because the reservation price can no longer be constant. If Bayesian updating is assumed, the reservation price will change with a consumer's experience. However, Rothschild (1974, p. 710) concludes his paper by mentioning that “without great loss” the qualitative properties can be assumed to be the same for both, search from known and unknown distributions.

The studies by Rothschild (1974) concerning search from an unknown distribution have been further examined by Talmain (1992) and extended to search with recall. Reservation prices are endogenous and, thus, depend on the model parameters. Since a reservation price changes due to experience, an offer that was rejected in a previous period may then be accepted. A searcher may be discouraged by bad experience and stop searching. Search from an unknown distribution induces less search if uncertainty increases (in terms of to what extent the searcher has to change its beliefs after making a new observation). This contrasts property 5 and the finding of Rothschild (1974) that increased uncertainty in terms of beliefs about the initial dispersion of prices reduces the intensity of search.

Wilde and Schwartz (1979, p. 543) address the question of "how much information is enough," which was discussed in the context of legal debates on disclosure of information to consumers. They assume that no consumer knows the price distribution. Observing consumer behaviour suggests that regardless of the price distribution there will be some consumers who always visit more than one store before purchasing. Their results are similar to those obtained by Salop and Stiglitz (1977), i. e. the higher the proportion of informed consumers, the lower is the average price in the market. The differences in results are caused by different assumptions on consumers' information.[25] While in the model of Salop and Stiglitz (1977) an equilibrium at the competitive price is only possible if a large proportion of consumers does not have positive search costs, Wilde and Schwartz (1979) show that in their model a competitive price equilibrium is even possible if all consumers have positive search costs. This is due to the fact that there are always some consumers who search more than once.[26] So, their implication towards legislation is that the provision of information to consumers will increase the competitiveness of markets and lower the average price.

The above-mentioned papers can be categorized roughly as 'first generation'. The authors of these papers are convinced that deviations from the "simplest model," for instance in the form of heterogeneous agents, are necessary to obtain a stable non-degenerate distribution of prices in equilibrium. That is, different prices result from the existence of positive search costs either combined with firms producing at different costs or consumers having different reservation prices.

Part II. In the papers of the 'second generation', conditions are analysed under what stable price distributions emerge, even if suppliers and consumers, are a priori identical. The main argument is that even if consumers, for instance, are a priori identical, ex post they will be heterogeneous because the search process is stochastic.

[25] In Salop and Stiglitz (1977) a consumer who searches once becomes fully informed.

[26] This can be interpreted as positive externality.

In contrast to REINGANUM (1979), BURDETT and JUDD (1983) consider even a simpler model. They were the first to show that an equilibrium with price dispersion can occur in models with both identical and rational suppliers and consumers.[27] This means that in contrast to the 'first generation', no a priori heterogeneity of costs, preferences or rationality is needed to explain the occurrence of non-degenerate price distributions in equilibrium. Only ex post heterogeneity in consumers' information is important: although consumers are identical ex ante, they receive different amounts of information since search is a stochastic process.[28]

The framework applied by BURDETT and JUDD (1983) consists of a large number of firms and consumers. The firms have identical and constant marginal costs and each firm charges its own price.[29] Consumers know the price distribution and either engage in non-sequential or in noisy sequential search. They buy one unit if the price does not exceed a certain level. If all observed prices exceed this limit, consumers will look for additional prices. Firms maximize their expected profits. Not only do the expected profits depend on the firms' own prices and on their competitors' prices, they also depend on the search method of the consumers. This in turn influences the market equilibrium. For both search methods, the only possible types of market equilibria are a monopoly price, a competitive price, and a dispersed price equilibrium. If non-sequential search with strictly positive search costs is assumed, the market equilibrium either will be a monopoly price equilibrium or a dispersed price equilibrium. All three types can be realized as market equilibrium for noisy sequential search. Furthermore, BURDETT and JUDD (1983, p. 967) point out that "[s]imilar results ... can be obtained if market entry by firms is allowed."

Assuming sequential search in the framework of BURDETT and JUDD (1983), ROB (1985) shows that the results will change. Equilibria with a single price between marginal costs and the monopoly price are only achieved if the proportion of low cost searchers is sufficiently large. For a monopoly price equilibrium, all consumers

[27] Remember that REINGANUM (1979) assumes cost differences and SALOP and STIGLITZ (1977) different search costs to obtain a price dispersion in equilibrium.

[28] And "the *ex post* heterogeneity may still occur when there is no *a priori* reason to expect it" (BURDETT and JUDD (1983, p. 956)).

[29] Unfortunately, they do not explain why identical firms announce different prices. This gap is filled later on by ACEMOGLU and SHIMER (2000).

must have identical and positive search costs. In all other cases, the price distribution is non-degenerate.

Rob (1985) further shows that concerning welfare properties, a one-price equilibrium is Pareto better than an equilibrium with dispersed prices.[30] A generalization of Burdett and Judd (1983) by Guimarães (1996) reveals that the success of policies to increase welfare depends negatively on the proportion of uninformed consumers. Further, he shows that some policies to increase the amount of information in a market may have the opposite effect, i. e. the average price rises. In a recent study, Janssen and Moraga (2000) give evidence for lower search costs that cause prices to increase. They argue that this may be one reason for the ambivalent evidence of the relationship between information and prices found in the internet markets. By introducing consumers' preferences for firms, Samuelson and Zhang (1992) show that an increase in search costs may lower prices.

Fershtman and Fishman (1992) extend the model of Burdett and Judd (1983) to a dynamic setting and show that consumers' search behaviour also can generate demand cycles. In contrast to the static model of Burdett and Judd (1983), they modify the consumers' search mechanism to account for the dynamics of the model in the following way. At the beginning of each period, a consumer decides how many price quotations he wishes to have received by the end of the period. Then, he can either accept the best offer or continue sampling. This search method combines fixed-sample-size search and sequential search, where the consumer is able to observe simultaneously an endogenously determined number of prices in each period. This means that consumers may search with different search intensities. A consumer can also decide not to observe prices and postpone his search and, consequently, his purchase. This behaviour may generate future demand booms. Firms are able to react to these booms by adjusting the product prices. As prices can be different each period, the only valuable information for consumers is the information about prices obtained in the current period. One result of this process is that the typical equilibrium price path is cyclical.

[30] Salop (1977) argues that search leads to a waste of resources and shows that dispersed prices cause a loss of welfare in a monopoly. On the contrary, Moen (1997) constructs a competitive equilibrium with search that is socially optimal. Welfare effects in the situation of erroneous beliefs are studied by Rauh (2001).

In the model, there is a continuum of identical firms and consumers. In each period, a new cohort of consumers of finite measure μ per firm enters the market. A consumer is characterized by an inelastic demand for one unit. Equally, he knows the sequence of future price distributions. Since consumers can delay their consumption, for each period $t > 1$ follows $\mu_t \geq \mu$. Each consumer has to decide about the number n_t of price quotations he intends to have received by the end of period t. For each quotation he has to pay a constant cost c. A consumer minimizes his total costs (search costs plus price) subject to a time preference rate $1/\delta$ to discount future flows of utility. $\delta > 1$ measures the impatience to consume and is chosen so that a consumer is indifferent between purchasing today at a price δp or tomorrow at a price p. A consumer buys if $\delta p \leq p$ and if the price is lower than or equal to his reservation price $\tilde{p}$. The latter is determined endogenously and depends on the current and on future price distributions, and on the search strategy.

Since firms are allowed to change the product prices each period, the information a consumer has in period t may be outdated in $t+1$. Therefore, a consumer can only buy from a firm from which he has received a quotation in the current period. For methodological convenience, the time horizon T is assumed to be finite and $T > 1$.[31]

Each firm charges its optimal price, being aware of the current price distribution and the search behaviour of the consumers, i. e. $\tilde{p}_t$ and the sequence $\{q_t^n\}_{n=0}^{\infty}$, where q_t^n denotes the probability for a randomly selected consumer to observe n prices. FERSHTMAN and FISHMAN (1992, pp. 1223) define a dynamic search equilibrium and its specific types as follows.

Given the time horizon T, $\{F_t(p), \pi_t, \mu_t, \{q_t^n\}_{n=0}^{\infty}, \tilde{p}_t\}_{t=1}^{T}$ defines a dynamic search equilibrium if

1. at every period t, given $(\mu_t, \{q_t^n\}_{n=0}^{\infty}, \tilde{p}_t)$, the profit of a firm is $\pi_t \geq 0$ if it asks a price in the support of $F_t(p)$ and is less than or equal to π_t if the product price lies outside the support; and

2. at every period t, $(\{q_t^n\}_{n=0}^{\infty}, \tilde{p}_t)$ represents the optimal search behaviour of consumers given the current and the future sequence of price distributions.

[31] According to FERSHTMAN and FISHMAN (1992) this assumption is not necessary. As for cyclical equilibria, the results apply directly to an infinite time horizon.

A stationary equilibrium is defined as a dynamic search equilibrium in which $F_{t_1}(p) = F_{t_2}(p)$ for every $t_1, t_2 \leq T$. A non-stationary dynamic search equilibrium for which there is an integer z, so that for every $t \leq T - z$, $F_t(p) = F_{t+z}(p)$, is called a cyclic equilibrium. Active demand at period t, AD_t, is said to be positive if a positive measure of buyers sample at least one price. $AD_t = 0$ if there is no search activity in period t and, therefore, no purchase is possible. A dynamic search equilibrium is characterized by endogenous booms if there are periods at which active demand is zero and other periods at which active demand is greater that μ.

In Fershtman and Fishman (1992), the results of Burdett and Judd (1983) are obtained as special cases. If all consumers sample only once, each seller will charge the monopoly price p^*. If the proportion of consumers who observe more than one price is positive, a dispersed price equilibrium will exist. Finally, if all consumers observe more than one price, the equilibrium price will equal the marginal cost price.

The equilibrium price distribution is determined by the equal-profit condition, given q and the monopoly price p^*. This condition implies that in equilibrium high-price firms sell fewer goods than low-price firms. The optimal search strategy of a consumer depends on the expected gain from search $G(\cdot)$ in the usual way, i. e. in equilibrium, the expected gain from an additional search equals its costs. As consumers search for at most two prices per period, the condition is simply

$$G(p^*, q) = c. \tag{2.2}$$

Given the reservation price p^*, a unique $c^* > 0$ exists that satisfies condition (2.2). If search costs exceed c^*, there is only one single-price equilibrium exists where all firms charge the reservation price. For $c = c^*$, a unique price-dispersed equilibrium exists, and if $c < c^*$, there are two dispersed price equilibria, a stable and an unstable one.

The reservation price depends on future price distributions and, thus, will not remain constant over the course of time. The endogenously varying reservation price influences the expected gain from search and the search intensity. In this way, there are periodical movements that generate cyclical price-dispersed equilibria for the stable and unstable case. The key element of this dynamic model is the possibly varying reservation price. The cyclical behaviour is induced by the obsolescence of information, the time preference of consumers ("impatience"), and their possibility of postponing purchasing if a future price distribution is more advantageous than the current. FERSHTMAN and FISHMAN (1992) demonstrate the establishment of cyclical price-dispersed equilibria for the stable and unstable case by a numerical example, and analyse the properties of the price and demand cycles. A disadvantage of this type of dynamic model is that the agents are assumed to have perfect foresight, i. e. they know the current distribution as well as all future price distributions.

PART III. As the impact of the main assumptions and the driving forces of price dispersions became acceptably clear, a new research interest emerged. Empirical observations became the focus of attention so that the assumptions of the models have been adjusted to the specific example that underlies a study. Most applications refer to the industrial organization literature.

In the dynamic search model of FISHMAN and ROB (1995), the starting point is the observation that in many economic sectors there are non-degenerate firm-size distributions and firms earn positive profits. Furthermore, large firms usually earn higher profits than small firms. FISHMAN and ROB (1995) explain these findings by positive consumers' search costs, which are interpreted as a measure of (im-)mobility in a market. Further, they argue that inter-industry differences in the correlation between profits and market shares can be explained by consumers' search behaviour.

FISHMAN and ROB (1995) assume consumers and firms to be identical. The consumers have a downward sloping demand curve, live infinitely, intend to purchase each period, and know the price distribution. To avoid that consumers may become (nearly) perfectly informed about all prices, it is assumed that they are only able to remember the price of the seller from whom they bought the previous period. Observing the price of this seller is free of charge in the next period. In order to obtain a price of another seller, a consumer has to pay a constant search cost c. Consumers search sequentially in each period and maximize their expected surplus, where the future surplus is discounted at a rate $\delta > 0$. The firms have the same constant marginal costs k. In contrast to the previously mentioned models, the costs vary over the course of time due to exogenous shocks, which are independently and identically distributed across the firms.[32] Only two states of costs are allowed, high costs k_H and low costs $k_L < k_H$. For an individual firm, marginal costs are an

[32] An example is inflation: although on average all agents are concerned equally, inflation is not the same for all factors of production. For example an oil price shock is more important for energy

autocorrelated random variable $\tilde{k}_t$ with a transition probability $1-\beta$ for which it is assumed that

$$\mathrm{P}(\tilde{k}_t = k_L | \tilde{k}_{t-1} = k_L) = \mathrm{P}(\tilde{k}_t = k_H | \tilde{k}_{t-1} = k_H) = \beta > \frac{1}{2} \qquad \text{and}$$

$$\mathrm{P}(\tilde{k}_t = k_L | \tilde{k}_{t-1} = k_H) = \mathrm{P}(\tilde{k}_t = k_H | \tilde{k}_{t-1} = k_L) = 1-\beta < \frac{1}{2}.$$

With probability β a firm remains in the cost state of the previous period and with probability $1-\beta$ the cost state changes. Prices can be adjusted without further costs, but a firm has to keep in mind that by increasing the product price it will lose patronizing customers. They will not return if the price is decreased because they are locked-in at another firm as long as this firm does not increase the product price. The transition probability influences also the returns from search if consumers buy repeatedly, i. e. the returns from search increase as β increases.

An equilibrium is characterized by a price distribution $F(p)$ so that firms maximize their discounted profits and consumers maximize their expected discounted surplus. Under the assumption of identical consumers, the equilibrium is called symmetric because prices only depend on the production costs. If consumers have different search costs, an asymmetric equilibrium can also be achieved, which is in line with the aforementioned empirical findings on the positive correlation between profits and firm size. The price is determined by the production costs and the market share of a firm and, thus, allows for different pricing policies of small and large firms. The most important result is that in the asymmetric steady state equilibrium large firms earn higher profits than small firms.[33] In the asymmetric equilibrium, the number of customers per firm varies. This enables firms that have low costs during a longer period ("successful" firms) to attract low-search-cost customers and to grow. Since the low-price firms would lose many customers if they increased the price to the same extent as their costs increased due to a cost shock, they do not fully adjust the product prices. Instead of charging a high price (as would be the case in the symmetric equilibrium), they prefer charging a medium price to keep most

intensive production than for a firm supplying labor-intensive services. For inflationary effects, see also TOMMASI (1992, 1994), FISHMAN (1992) and BÉNABOU and GERTNER (1993).

[33] Up to now an equilibrium has been characterized by an equal-profit condition.

of their customers. Less successful firms will charge a high price if confronted with an increase in costs. Thus, concerning low costs, all firms behave identically, but concerning high costs, successful firms charge lower prices than less successful firms. Therefore, successful firms will grow faster. The results concerning the asymmetric equilibrium are as expected, i. e. uncertainty leads to higher prices and a larger variance, and an increased purchasing frequency decreases both.

The model of Fishman and Rob (1995) offers an explanation for the phenomenon that firms charge different prices and vary in profits. Concerning search, consumers only have an incentive to change their supplier if the price is increased above their reservation price due to exogenous shocks. Fishman and Rob (1995) emphasize the dynamic aspects of the theory by mentioning that their equilibrium arises along an equilibrium path depending on initial conditions. By the way, evolutionary concepts are mentioned: path dependence, critical mass, accumulation of knowledge, lock-in. Following this idea, it would be possible to interpret the positive cost shocks as successful innovations which secure profitability for some periods. To remain powerful, a firm has to strengthen its position because competitors also innovate. After a while, the first firms would have been driven out of the market because their technology was no longer competitive. This means that the cost shocks could not be totally random because they depend on R&D efforts of the firms. Additionally, the model of Fishman and Rob (1995) explains why small enterprises are able to survive and co-exist in the same market with large firms.

Another strand of papers concerns the price distortions caused by macroeconomic shocks, such as inflation. Inflation is one source of cost dispersion and, therefore, an explanation of the exogenous cost shocks. Because the effects of inflation are manifold,[34] the result of Rothschild (1974) is no longer valid, i. e. the results hardly differ regardless of whether consumers know the price distribution. For the models concerning inflation it is a natural assumption that consumers do not know the price distribution and must acquire information about prices because the effects of a shock cannot be anticipated.

Dana Jr. (1994) analyses search behaviour with unknown but exogenous price distributions and describes the relationship between consumers' learning and price dis-

[34] Inflationary shocks may be of uniform or idiosyncratic nature, and the price adjustment in the situation of negative and positive shocks is usually not symmetric.

persion when there is incomplete information about firms' costs. His model extends the model of Varian (1980) in two ways: cost realizations are private knowledge of the firms and uninformed consumers are able to engage in fixed-sample-size search. So, the model deals with incomplete information instead of imperfect information. While Rothschild (1973) and Talmain (1992), for instance, assume the price distribution to be exogenous, Dana Jr. (1994) assumes incomplete information in the way that consumers do not know whether a firm has high or low costs. Consequently, not only do consumers have to ensure different prices, they also have to obtain information about the market conditions. It is assumed that the marginal costs of firms are common knowledge, but the cost shocks are not observable by consumers. There is a proportion of uninformed consumers who can engage in fixed-sample-size search, and after searching once they become fully informed. The other proportion of consumers is completely informed from the beginning and buys from the cheapest supplier. Dana Jr. (1994) shows[35] that under incomplete information prices are less sensitive to cost shocks than they are under complete information. Compared to complete information, the degree of price dispersion under incomplete information is higher if costs are high and lower if costs are low. The uncertainty on the consumers' part causes the average price to be high. Further, consumers search more if costs are high. This explains asymmetric price adjustments, i. e. the decrease in price caused by a cost decrease is larger than the price increase induced by increased costs. These results correspond to those of Bénabou and Gertner (1993) and Fishman and Rob (1995). For this phenomenon, empirical evidence is given, for instance, by Reinsdorf (1994).

In a model where consumers search from an unknown price distribution, Bénabou and Gertner (1993) show how the price distribution is influenced by cost shocks. They assume that buyers do not know whether the shocks are specific to the observed seller or whether it is an aggregate shock experienced by all sellers of an industry as, for instance, an oil price shock or inflation. They demonstrate that the welfare effects of aggregate cost shocks depend on search costs. If search costs are high, consumers' adaptive search leads to an increase in firms' market power and vice

[35] Using an oligopoly approach as implemented, for instance, in Butters (1977) and Burdett and Judd (1983) under the assumption of complete information.

versa. For high search costs the equilibrium is characterized as qualitatively similar to REINGANUM (1979).

The model of FISHMAN (1996) is also related to DANA JR. (1994) and BÉNABOU and GERTNER (1993). He compares the search theoretic approach with the theory of small menu costs and concludes that the former fits better to empirical data because the price adjustments after positive or negative cost shocks are not symmetric. The theory of small menu costs has many weak points and does not provide as many insights as provided by a search theoretic approach. In his two-firm model, FISHMAN (1996) makes a distinction between short run and long run effects of cost changes, and uniform shocks as well as idiosyncratic shocks. The model is mainly created to study price adjustments caused by macroeconomic shocks.[36]

Another explanation of the existence of non-degenerate price distributions is given by AGHION et al. (1993). In their oligopoly model, the agents who will learn are the firms. Firms are assumed to be uncertain about demand conditions concerning the substitutability of a horizontally differentiated product.[37] Learning takes place by experimentation. It is shown that price dispersion is negatively related to the information of the firms and may vanish as firms become completely informed. Price dispersion only occurs as short-run phenomenon caused by a lack of information about the supply side and not by search costs of the consumers.

In contrast to the exogenously given demand in AGHION et al. (1993), in the model of FISHMAN and ROB (1998) consumers' are assumed to be uncertain about the prices. They analyse a monopoly as well as two types of duopoly, where the former is of less interest here. In the duopoly case, there are two identical, infinitely-lived firms with constant marginal costs. There are two types of consumers, one group with a high reservation price, p_H, and one with a low reservation price, p_L, where it is assumed that the proportion of high and low reservation price customers remains constant. In each period, one customer arrives in the market and is matched randomly to one of the two firms. He can observe the price of the first firm free of charge, but observing the price of the other firm causes search costs c. The consumer either buys one unit

[36]Further papers related to macroeconomic shocks are, for instance, FISHMAN (1992), who analyses price adjustments after nominal disturbances in a Keynesian context, and TOMMASI (1992, 1994), who shows effects of inflation and quantifies the welfare loss caused by inflation.

[37]In all other models that are described in this section homogeneity is assumed.

or leaves the market without purchasing, and another consumer enters the market in the next period.

The firms are imperfectly informed about demand. They know p_H and p_L, but they neither know the proportion of high reservation price consumers nor the type of the consumer who currently visits them. A firm has to decide at what price it intends to sell its product. The firm charges either p_L and will sell the product certainly, but it does not learn anything about the demand or the firm experiments with a price $p_L < p \leq p_H$ in order to acquire information about the demand and to increase its expected profits. Learning is beneficial since the proportion of high reservation price customers remains constant. A firm has prior beliefs about this proportion, and the beliefs are updated after each experiment (where firms only can learn from experiments with $p > p_L$). Experimentation and the willingness to learn about demand depend on the firms' beliefs and on the extent of competition. Fishman and Rob (1998, p. 300) argue that "search is a natural measure of competition in this setting", where low search costs indicate high competition and vice versa.

Fishman and Rob (1998) show that for all three cases — monopoly, duopoly with private information and duopoly with public information — the results are identical: competition leads to less experimentation by firms. They learn less about demand and, in consequence, they charge lower prices. Experimentation can lead to price dispersion. Depending on the search costs, a consumer may have an incentive to search if matched to a firm that charges a price above p_L. This, in turn, may compel the firm to lower the price for not to lose its customers to the competing firm. On the one hand, higher expected profits are an incentive to experiment, but, on the other hand, this incentive is thwarted by the risk of losing customers and, therefore, decreasing profits at least in the short run. In a duopoly with firms' private information about demand, information is the source of price dispersion because the sellers may draw different conclusions from their experiments concerning the underlying demand. There are fewer incentives to experiment if information is a public good because the experimenting firm bears the risk of losing customers whereas the other firms can use this information free of charge. Without experimentation (i. e. very low search costs) in equilibrium all firms charge the monopoly price p_H.

Consumers search with a higher intensity for a low price the lower their search costs are. Low search costs are interpreted as strong competition among the firms.

The main result of Fishman and Rob (1998) is that higher competition leads to less learning and lower prices. In a price dispersed equilibrium the highest price is charged so that high reservation price customers do not search. A one price equilibrium is either characterized by the low price p_L (high competition, low search costs) or by the monopoly outcome p_H (low competition, high search costs). Although the main results for the three cases analysed are similar, the resulting price paths differ, i. e. depend on the model parameters, such as search costs, demand uncertainty, and the status of information. A downward sloping price path can be observed if information is a private good. Otherwise, the price path may be upward sloping or cyclical. Fishman and Rob (1998) give a microeconomic explanation of the price path which reflects the empirical observation that, over the course of time, prices vary according to the life cycle of a product.

Fishman and Rob (1999) analyse the relationship between a firm's customer base and its R&D expenditures where cost shocks force production costs up. Consumers have positive search costs. If they once bought from a certain supplier, they only start searching again if the supplier increases the price due to a cost shock above their reservation price. Firms are constrained to sell goods to their customer base only, so that, given a price shock, a firm faces a trade-off between increasing the product price and losing some customers forever. It is shown that firms with a higher customer base spend more money on R&D, have lower costs on average and, therefore, lower prices. The new main feature of this model is that firms cannot sell any quantity they intend to.

A totally different approach to model price dispersions is offered by Wolinsky (1983).[38] He follows the insight that the results of Diamond (1971) do not hold if one of his assumptions is modified.[39] Applying game theoretic methods, Wolinsky (1983) provides a solution that differs from the papers mentioned above. The hypothesis of Wolinsky (1983, p. 117) is that the "common results are sensitive to the form of the buyer-seller interaction, whose important role is ignored by most market models." In order to show this dependency, he constructs a model where

[38] This approach belongs to the game theoretic bargaining literature. For an overview, see McMillan and Rothschild (1994, pp. 916). Further game theoretic approaches are, for instance, Anderlini and Ianni (1996) who model price dispersion as result of local interaction, and Hopkins and Seymour (1996), which is an evolutionary extension of Burdett and Judd (1983).

[39] See also Reinganum (1979), Butters (1977) and Salop and Stiglitz (1977).

consumers can bargain the announced price down by committing themselves to a price below that asked by the seller. If the seller accepts, the consumer buys one unit, otherwise he searches for another seller. Concerning equilibrium prices, the "standard" results are confirmed: consumers with higher (lower) search costs pay higher (lower) prices. A further kind of price dispersion is developed: in this model, different consumers may end up paying different prices to the same seller.[40] Not only does Wolinsky (1983) offer an explanation for dispersed prices among shops, he also offers an explanation for varying prices within the same shop.

The approach of Wolinsky (1983) allows to elude the weak point of the above-mentioned models that firms' behaviour is not sub-game perfect, i. e. it is not rational concerning the aim of maximizing profits. If firms behaved as profit maximizers, they would bargain with those consumers who do not accept the product price. Following the arguments of Jovanovic (1984, p. 111), this problem of inconsistency vanishes, for instance, if it is assumed that contracts between firms and individuals are legally enforceable or by treating the consumers in different ways the firm loses reputation. van den Berg and Ridder (1998, p. 1193) state that their model with individuals who search permanently "shares some of the fundamentals of a bargaining framework" because the "model reflects the bargaining power of both sides of the market".

In contrast to the labor market model of van den Berg and Ridder (1998), in the models outlined above, consumers search only once and leave the market thereafter or, if they buy repeatedly, search is only triggered by a price increase.[41] Mortensen and Neumann (1988) — the predecessors of van den Berg and Ridder (1998) — were the first to introduce consumers who search permanently, i. e. consumers who have already found a supplier continue searching even if their supplier has not changed the price. In general, labor market search models are structurally similar

[40] Intra-firm price dispersion is also established by Dana Jr. (1999) but by using a framework in the way of Burdett and Judd (1983) with demand uncertainty. Other models of bargaining are provided by Daughety and Reinganum (1991) where they analyse the impact of market structure on the amount of the good provided and Ponsatí and Sákovics (1999) including outside options.

[41] Some of the models incorporating at least repeated search are Burdett and Coles (1997), McMillan and Morgan (1988), and the overlapping-generations models of Salop and Stiglitz (1982) and Diamond (1987).

to the price search models, but they work from a different perspective.[42] The only contribution to labor market economics to describe in detail is Bontemps et al. (2000). For a better presentation and because their model is going to be implemented into the evolutionary simulation model of Winter (1984), it is transformed to fit the notion of a model where consumers search for the lowest price. The model of Bontemps et al. (2000) is outlined in the following Section 2.3.

The search models outlined so far are concerned with analysing search behaviour and its impact on equilibrium. All of them assume that as soon as a consumer has found a supplier he stops searching. The only reason for continuing search is an increase in the seller's price.[43] In the static search models, consumers are only required to search once (e. g. Butters (1977)) or some of them at most twice (e. g. Reinganum (1979)).

Since it is now common knowledge that non-degenerate price distributions are a stable equilibrium outcome and are sustained by very weak assumptions, research is focussed on other phenomena, such as the impact of cost shocks like inflation on the efficiency of allocations, effects of search frictions, and welfare effects of policy changes.

The empirically-oriented strand of economic literature tries to improve the explanation of real-world phenomena, such as unemployment. A major improvement here is the approach of Mortensen and Neumann (1988), who first analysed on-the-job search. In their dynamic model, workers do not cease searching after accepting a job.

In the context of this thesis, this implies that consumers who are customers of a certain supplier do not stop looking for other price offers. This is, indubitably, in sharp contrast to the models outlined in the previous section. In the job market research, this approach leads to valuable insights and has a very good fit, for instance, to French labor market data.[44] Applied to a consumer goods market, the assumption

[42] Job search models can be divided into computational/experimental (e. g. Tesfatsion (2001)), theoretical (e. g. Burdett and Mortensen (1998), Jovanovic (1984)), and empirical approaches (e. g. Bontemps et al. (2000)). For an overview it is referred to the surveys by Lippman and McCall (1976a,b), and Mortensen (2001).

[43] See e. g. Fishman and Rob (1999).

[44] See e. g. Bontemps et al. (2000) and Bontemps et al. (1999).

that consumers never cease searching seems reasonable in some ways. First, prices are usually not constant, not even at a single firm. This implies that information becomes outdated and the consumer cannot be sure that his supplier will be the best choice forever. Second, the changing price distribution affects consumers' reservation price, i. e. the higher the mean of a price distribution, the higher is the consumers' willingness to pay.

2.3 When Consumers Never Cease Searching

The model presented in this section is the dynamic search model of Bontemps et al. (2000). Their investigations base largely on the work by Mortensen and Neumann (1988), the extensions by van den Berg and Ridder (1998), and Bontemps et al. (1999). All models allow a structural approach to estimate a search model as initiated by Eckstein and Wolpin (1990). Their estimations of a search model that only allows search by unemployed shows a poor fit to the wage data,[45] and it became obvious that further research into the direction of on-the-job search is desirable. One advantage of the structural estimation method is that only few data are needed (mainly duration data) and that the estimation model takes into account the restrictions of the theory. In the model of Eckstein and Wolpin (1990) it is assumed that workers are heterogeneous with respect to their reservation wage in order to obtain a wage distribution. Together with the restriction that only unemployed workers are allowed to search, van den Berg and Ridder (1998) consider this to be the main reason for the poor empirical fit. Mortensen and Neumann (1988) propose a structural estimation model to allow for on-the-job search and homogeneous agents, but they only give Monte Carlo evidence. This model was empirically tested by van den Berg and Ridder (1998). In contrast to Eckstein and Wolpin (1990), their estimations on duration spells are consistent with the French labor market data, and only a small fraction of the wage dispersion remains due to measurement error. Instead of between-market heterogeneity (created by dividing the market into many segments) Bontemps et al. (2000) allow for within-market heterogeneity and assume that firms have different

[45] Eckstein and Wolpin (1990, p. 785) comment that the estimations "imply that almost all of the observed wage dispersion is due to measurement error."

technologies. Considering their estimates, Bontemps et al. (2000, p. 330) state to have a "perfect fit to the wage data."

One can hardly expect to obtain the data necessary for estimating such a structural search model in a consumer goods market. Not only is the model of Bontemps et al. (2000) chosen for the synthesis in this thesis because of its good fit to the data, but also because the mechanisms operating in the consumer goods markets seem to be very similar. This is, many consumers are permanently looking for cheaper prices.

In Bontemps et al. (2000), heterogeneity by nature among individuals is not allowed because it only can explain a small fraction of wage variation. The assumption of homogeneous consumers is maintained in this study in order to keep the analysis tractable.[46] In the remainder of this chapter, the transformed model of Bontemps et al. (2000) is presented without referring further to the labor market terminology.

2.3.1 Consumer Behavior

In the market, there are N consumers who may be in two states: A participant of the market can either be an actual customers who has made a transaction in the previous period(s), or a potential consumer who searches for a supplier either because he has not found a supplier yet or because his last supplier has gone bankrupt. The measure of the actual customers is E, the measure of potential consumers is U, and $E+U=N$. The state of a consumer may change from period to period. The probability of a supplier to go bankrupt is given by a constant rate ζ.[47] A potential consumer obtains a price offer at a constant rate λ_0, and an actual customer receives a price offer at a constant rate λ_1. It is assumed that $\lambda_1 \leq \lambda_0$ because the actual customers are not as attentive to price offers as potential consumers. $\lambda_i, i = 0, 1$ reflects the optimal search intensity chosen by wealth-maximizing potential consumers and actual customers, respectively. All consumers are assumed to search sequentially. Therefore, whenever a consumer obtains a price offer, he has to decide whether to accept the offer or reject it. Sequential search is characterized by the reservation price property as outlined in

[46] For an extension by heterogeneous workers, see Bontemps et al. (1999).

[47] Firm behaviour is described in detail in Section 2.3.3, pp. 61.

Section 2.2. Consumers maximize their expected steady-state future gain of search subject to constant search costs per visited firm.[48]

There are opportunity costs b of consuming the good instead of spending the money for another good or to save it. This can be interpreted as a measure of household income, i. e. if b is high, the household income is high and, therefore, the willingness to pay for a normal good is also high and vice versa.[49]

The price offer variable P is a random variable. A price offer of a firm, p, is drawn from a cumulative distribution function $F_P(p) = \text{Prob}(P \leq p)$, which is specified below. The distribution of price offers, $F_P(p)$, is independent of the state of the consumer (actual customer or potential consumer). The price offer distribution is known to the consumers. Denote by $\text{supp}(F_P)$ the support of $F_P(p)$, where $\underline{p}$=inf[supp(F_P)] and $\bar{p}$=sup[supp(F_P)] with $\underline{p} \geq 0$.

The optimal strategy of a consumer is implicitly given by the following proposition.[50]

Proposition 2.1 *The optimal strategy when new in the market is to accept any price offer $p \leq \varphi$, where φ, the reservation price, is implicitly defined as:*

$$\varphi = b + (\lambda_0 - \lambda_1) \int_{\underline{p}}^{\varphi} \frac{F_P(x^+)}{\zeta + \lambda_1 F_P(x^+)} \, dx \tag{2.3}$$

$$= b + (\kappa_0 - \kappa_1) \int_{\underline{p}}^{\varphi} \frac{F_P(x^+)}{1 + \kappa_1 F_P(x^+)} \, dx \tag{2.4}$$

with $\kappa_0 = \lambda_0/\zeta$ and $\kappa_1 = \lambda_1/\zeta$.

The optimal strategy for an actual customer is to accept any price offer strictly[51] *lower than the present one.*

[48] These may also be discounted, but without loss of generality the discount rate is set equal to zero.

[49] It also may be economic pressure instead of willingness. For low income households this may lead to the Giffen effect that the demand increases if the price is increased. But Giffen goods are not the subject of this study.

[50] See BONTEMPS et al. (2000, p. 309), MORTENSEN and NEUMANN (1988, p. 344), and VAN DEN BERG and RIDDER (1998, p. 1187).

[51] Whether an equal price offer would be accepted depends on the type of the good. Changing the supplier of a standardized good usually will not cause much troubles, when it is assumed that the consumers do not have preferences for a certain supplier or other switching costs.

Since Equation (2.3) includes price offer distributions with mass points, it has to be used $F_P(x^+) := \lim_{\varepsilon \uparrow 0} F_P(x+\varepsilon)$ instead of $F_P(x)$.[52] The average price offer $E_{F_P}[p]$ is assumed to be finite. As a consequence, the reservation price φ is finite as well as $\bar{p}$=sup[supp(F_P)].

Firms do not offer a price $p > \varphi$ because otherwise, they would not sell anything and would not participate in the market any more. Thus, $\bar{p} \leq \varphi$.

2.3.2 Steady-State Equilibrium Consumer Flows

In this model, there are two price distribution functions which have to be clearly distinguished, namely $F_P(p)$ = Prob($P \leq p$) and $G_P(p)$ = Prob($P \leq p$). $F_P(p)$ is the cumulative density of prices offered by the active firms, also called the price offer distribution. On the contrary, $G_P(p)$ is the cumulative density of the prices actually paid by consumers, i. e. those prices at which trade takes place in the market. Therefore, supp[G_P] $\subseteq$ supp[F_P]. Then, $\bar{G}_P(p) = 1 - G_P(p)$ can be interpreted as the fraction of consumers who pay a price strictly higher than p in the stock of actual customers.

If it is considered that all consumers buy at a price strictly higher than p, the following consumer movements can be identified in any interval $[t, t+dt]$ in a steady state demographic equilibrium.

A. Potential consumers are willing to accept any $P > p$ if $p \leq \varphi$. So, the flow from potential consumers (U) to actual customers (E) is

$$\lambda_0 \cdot \bar{F}(p) \cdot U \cdot dt,$$

where $\bar{F}(\varphi^+) = 0$.

B. With the constant rate λ_1, experienced consumers are able to improve their situation, i. e. to find a firm that offers a price which is strictly lower than the price they have paid so far. The flow of customers moving from their old supplier to another equals

$$\lambda_1 \cdot F(p) \cdot E \cdot \bar{G}(p) \cdot dt.$$

[52] See Bontemps et al. (2000, p. 310).

C. The flow of "unlucky" consumers, i. e. those who move from consumption (E) back to the "unsatisfied" state (U) because the firm at which they bought the product the previous period has gone bankrupt, is given by

$$\zeta \cdot E \cdot \bar{G}(p) \cdot dt.$$

In Figure 2.1, all of the described consumer movements are summarized, where the letters in circles refer to the specified flows.

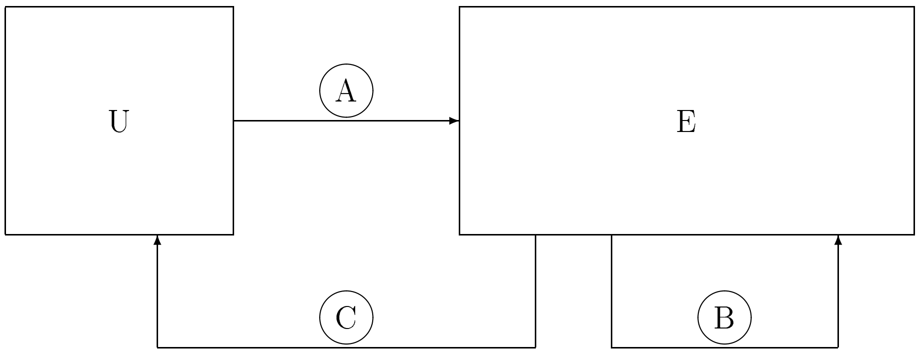


Figure 2.1: Consumer Movements

In equilibrium, the flows in and out of the stock of actual customers who pay a price strictly above p must be identical. Equalling A with the sum of B and C gives

$$\begin{aligned} \lambda_0 \cdot U \cdot \bar{F}_P(p) &= \zeta \cdot E \cdot \bar{G}_P(p) + \lambda_1 \cdot F_P(p) \cdot E \cdot \bar{G}_P(p), \qquad \text{or} \\ \lambda_0 \cdot U \cdot \bar{F}_P(p) &= (N - U) \cdot \bar{G}_P(p) \cdot [\zeta + \lambda_1 F_P(p)] \end{aligned} \tag{2.5}$$

if $p \leq \varphi$, and flows are zero if $p > \varphi$.

For $p = \underline{p}$, it is $F_P(p) = G_P(p) = 0$ and $\bar{F}_P(p) = \bar{G}_P(p) = 1$, and Equation (2.5) implies that

$$\lambda_0 \cdot U = \zeta(N - U) \qquad \text{or} \qquad \frac{U}{N} = \frac{\zeta}{\lambda_0 + \zeta} = \frac{1}{1 + \kappa_0} \tag{2.6}$$

where $\kappa_0 = \frac{\lambda_0}{\zeta}$.

To sum up, the following proposition can be maintained.[53]

Proposition 2.2 *In a steady-state demographic equilibrium, one must have that*

$$\frac{U}{N} = \frac{1}{1+\kappa_0} \qquad \textit{and} \tag{2.7}$$

$$\bar{G}_P(p) = \frac{1 - F_P(p)}{1 + \kappa_1 \cdot F_P(p)}, \tag{2.8}$$

with $\kappa_0 = \frac{\lambda_0}{\zeta}$ *and* $\kappa_1 = \frac{\lambda_1}{\zeta}$.

Equation (2.7) confirms that the proportion of "unlucky" consumers increases with the bankruptcy rate ζ and decreases with the search effort λ_0. Equation (2.7) is obtained by equalling the flows into and out of U.

Equation (2.8) gives the structural relationship between the distribution of actually paid prices, $G_P(p)$, and the price offer distribution $F_P(p)$ which is imposed by the steady-state demographic equilibrium, e. g.

$$\begin{aligned} F_P(p) = 0 \quad &\Rightarrow \quad G_P(p) = 0, \\ F_P(p) = 1 \quad &\Rightarrow \quad G_P(p) = 1, \\ F_P(p) = \tfrac{1}{2} \quad &\Rightarrow \quad G_P(p) = \tfrac{1+\kappa_1}{2+\kappa_1}. \end{aligned}$$

This means that if the price offer distribution $F_P(p)$ is given, in equilibrium the distribution $G_P(p)$ of actually paid prices can be determined, given that the parameters κ_0, κ_1, or $\lambda_0, \lambda_1, \zeta$ are exogenous.[54] For $\kappa_1 > 0$ and a price p it always holds that $F_P(p) \leq G_P(p)$, i. e. as theory imposes, high-price firms are driven out of the market.

[53] See BONTEMPS et al. (2000, p. 310).

[54] One could also imagine that search intensities depend, for instance, on the ratio of firms to consumers, as suggested by BONTEMPS et al. (2000, p. 311).

2.3.3 Behavior of Heterogeneous Firms

From the price offer distribution $F_P(p)$ it follows that a consumer receives a price offer above p with probability $\bar{F}_P(p) = \text{Prob}(P > p)$. The problem of how consumers and firms can be matched on the market is solved by the assumption that consumers draw price offers by randomly picking firms, where all consumers use a uniform sampling scheme.

Let Z denote the measure of active firms. A firm is called active if it is able to sell at least one unit of its product. It is called *potentially* active if it offers goods at a price that does not exceed the reservation price of the consumers, i. e. $p \leq \varphi$, or $p \in \text{supp}[F_P(p)]$. Although a firm may have the possibility of carrying out price discrimination among its customers, it is assumed that each firm offers only one price to all its customers. All firms intend to expand by increasing their market shares. $Z \cdot \bar{F}_P(p)$ is the measure of firms offering a price above p. They can be related to $E \cdot \bar{G}_P(p)$, which is the measure of consumers paying a price above p. It follows that the steady-state number of customers per firm paying p is[55]

$$l(p) = \frac{E}{Z} \cdot \frac{d\,\bar{G}_P(p)}{d\,\bar{F}_P(p)} = \frac{E}{Z} \cdot \frac{1 + \kappa_1}{[1 + \kappa_1 F_P(p)][1 + \kappa_1 F_P(p^+)]}, \tag{2.9}$$

where $d\,G_P(p)$ and $d\,F_P(p)$ are the densities of $G_P(p)$ and $F_P(p)$.

Given the model parameters, then, for a firm offering a price p, $l(p)$ gives the number of customers out of E the firm can expect in the current period. A firm offering $p = \bar{p}$ can expect $l(p) = \frac{E}{Z}\frac{1}{1+\kappa_1}$ customers (since $F(p^+) = F(p) = 1$), whereas a firm offering $p = \underline{p}$ can expect $l(p) = \frac{E}{Z}(1 + \kappa_1)$ customers (since $F(p^+) = F(p) = 0$). This means that the number of expected customers of a high price firm is below the average, and the number of expected customers of the low-price firms is above the average. A firm can expect to attract the more customers, the lower the price is. Thus, the function $l(p)$ decreases in p on $\text{supp}[F_P(p)]$.[56] This is also economically plausible because a low-price firm has two chances of obtaining customers. First, it receives customers out of the flow from U into E (flow A). Second, it can attract

[55] This corresponds to the Radon-Nykodin density of distribution $E \cdot \bar{G}_P(p)$ with respect to $Z \cdot \bar{F}_P(p)$. A more general form of $l(p; \cdot)$ is given by Burdett and Mortensen (1998, p. 261).

[56] This is easy to verify since $l(p)$ monotonically decreases in $F_P(p)$ and $F_P(p)$ monotonically increases in p.

customers of high-price firms who improve their situation within E (flow B). A high-price firm has the same probability of obtaining customers out of U as a low-price firm of equal size, but with an increasing price the second chance shrinks or changes to the contrary so that the firm loses its customers in competition with lower-price firms. If at last there is no search by actual customers, i. e. $\lambda_1 = 0$, then $F_P(p) = 0$, $F_P(p^+) = 1$, $\kappa_1 = 0$ and $l(p) = \frac{E}{Z}$, i. e. the expected number of consumers per firm is the same for all firms, regardless of the product price they offer. In other words, the consumers are uniformly distributed across firms.

Producing the good causes constant marginal costs γ.[57] Among firms, production costs may differ and are distributed according to the cumulative density function $\Omega_0(\gamma)$ with infimum $\underline{\gamma}_0 \geq 0$ and supremum $\bar{\gamma}_0$. Production costs are assumed to have a finite mean, i. e. $E_{\Omega_0}[\gamma] < \infty$. $\Omega_0(\gamma)$ is the distribution of γ that prevails if all *potentially* active firms have entered the market. The fact that a firm offers its good at a certain price $p \leq \varphi$ does not guarantee that trade will take place. A firm with production costs γ is called a firm of type γ.

Firms are assumed to maximize their market share, which is equivalent to maximizing their steady-state profit flow if marginal costs are constant. Expected profits are given by

$$\pi(p, \gamma) = (p - \gamma) \cdot l(p), \qquad (2.10)$$

where $p - \gamma$ is marginal profit and $l(p)$ represents the expected number of customers as given by Equation (2.9) if all consumers maximize their expected wealth and all other prices are distributed according to $F_P(p)$. Consequently, a firm does not offer a price below its marginal costs because profits would become negative. Additionally, as already mentioned, the maximum price offer does not exceed the consumers' reservation price, i. e. $\bar{p} \leq \varphi$.

A necessary condition for production (supply) is that $\text{Prob}_{\Omega_0}(\gamma < b) > 0$, which ensures positive gains from trade. This implies that for $b = \bar{\gamma}_0$ some firms go

[57] This is assumed for convenience. Instead, γ could also be a cost *function* depending on output or a technology, respectively. As a consequence, a firm's behaviour may change, particularly if its marginal costs are increasing because there is a capacity constraint with respect to profit maximization.

bankrupt if b decreases. No direct bankruptcy follows for $b > \bar{\gamma}_0$ and, thus, market structure does not change.

Denote the supremum cost of production that allows non-negative profits by $\bar{\gamma}$ and the cumulative density function of production costs of *active* firms by $\Omega(\gamma)$. Then, $\Omega(\gamma)$ can be expressed in terms of $\Omega_0(\gamma)$ as

$$\Omega(\gamma) = \frac{\Omega_0(\gamma) - \bar{\Omega}_0(\bar{\gamma})}{\Omega_0(\bar{\gamma})},$$

with $\gamma \leq \bar{\gamma} \leq \min\{\bar{\gamma}_0, \varphi\}$.

It follows that the measure of active firms, Z, is endogenous:

$$Z = Z_0 \cdot \Omega_0(\bar{\gamma}),$$

where Z_0 is the measure of *potentially* active firms.

All firms aim at increasing their market share because of the constant marginal profit,[58] i. e. they maximize profits given their production costs. It is possible that the same profit level can be achieved at different prices. Thus, firms of the same cost type may offer different prices. This means that identical firms may differ in their pricing strategies. The set of optimal strategies, S_γ, contains those values of p that maximize profits and is given by

$$S_\gamma = \arg\max_p \{\pi(p, \gamma) | \gamma \leq p \leq \varphi\} \tag{2.11}$$

with

$$\pi(p, \gamma) = (p - \gamma) \cdot \frac{E}{Z_0 \cdot \Omega_0(\bar{\gamma})} \cdot \frac{1 + \kappa_1}{[1 + \kappa_1 F(p)][1 + \kappa_1 F(p^+)]}.$$

If consumers are not allowed to change their supplier, this result is equivalent to the monopoly solution of Diamond (1971). If no consumer can improve his situation (flow B is zero), then $\lambda_1 = 0$, and, therefore, $\kappa_1 = 0$. Maximizing profits means maximizing the difference $p - \gamma$, which has its maximum at the highest possible price. Thus, prices are monopoly prices, i. e. $p = \varphi$ for all firms.

[58] Excluding the case that a positive mass of firms have $\gamma = \varphi$ because then, profits would be zero and a firm would have zero profits regardless of its market share.

If $\kappa_1 > 0$ and the set S_γ contains more than one price, firms will be indifferent between the alternative pricing strategies. Before entering the market, firms have to choose a price strategy. It is assumed that firms put probabilities symmetrically on each element of S_γ. Then, a firm's strategy is characterized by a probability distribution over S_γ, from which one element is chosen before entering the market.[59]

Denote by $F(\cdot;\gamma)$ the strategy for type γ firms, which is a probability distribution over the set S_γ. The individual price strategies can be aggregated to the price offer distribution

$$F_P(\cdot) = \int_\gamma F(\cdot;\gamma) \cdot d\,\Omega(\gamma). \tag{2.12}$$

In this way, the distribution $F(\cdot;\gamma)$ becomes independent of γ so that $F_P(p)$ contains all admitted profit maximizing prices for all possible cost states.

2.3.4 Market Equilibrium

In the following definition, the behaviour of consumers and firms are combined to describe the market equilibrium. Equally, some characteristics of the equilibrium are outlined.[60]

Definition 2.1 *A market equilibrium is a triple* $(\varphi, \bar{\gamma}, \{F(\cdot;\gamma), \gamma \leq \bar{\gamma}\})$ *so that*

1. *the distribution of price offers in the economy is*

$$F_P(\cdot) = \int_\gamma F(\cdot;\gamma) \cdot d\,\Omega(\gamma),$$

2. *only firms with production costs* $\gamma \leq \bar{\gamma}_0$ *are active, and the distribution of their costs is*

$$\Omega(\gamma) = \frac{\Omega_0(\gamma) - \bar{\Omega}_0(\bar{\gamma})}{\Omega_0(\bar{\gamma})},$$

[59] Assuming that there are several profit maximizing prices is very general. In Chapter 3 it will be pointed out under which conditions $S_\gamma = S(\gamma)$ holds, i. e. when a unique maximum exists. See BONTEMPS et al. (2000, p. 315, Proposition 3).

[60] See BONTEMPS et al. (2000, p. 313).

3. *φ is consumers' best response to firms' aggregate behaviour, i. e.*

$$\varphi = b + (\lambda_0 - \lambda_1) \int_{\underline{p}}^{\varphi} \frac{F(x^+)}{\zeta + \lambda_1 F(x^+)} dx, \qquad \text{and}$$

4. *the strategy of each type γ firm is to randomly draw a price from probability distribution $F(\cdot;\gamma)$ that puts positive probability on the set S_γ of profit-maximizing prices of type γ firms given other firms' and consumers' strategies, i. e.*

$$S_\gamma = \arg\max_p \{\pi(p,\gamma) | \gamma \leq p \leq \varphi\}$$

with $\pi(p,\gamma)$ defined by Equation (2.11).

In Burdett and Mortensen (1998), the equilibrium is described in detail. They prove that there is a unique solution. If it is assumed that there are active customers who search permanently (i. e. $\lambda_1 > 0$), an equilibrium with a non-degenerate price distribution is a robust outcome. This holds for homogeneous as well as for heterogenous consumers. The condition that $\lambda_1 > 0$ is necessary and sufficient for obtaining a non-degenerate price distribution, i. e. it does not matter whether firms are homogeneous or not. The equilibrium price distribution F_P is continuous and has a connected support. The maximum price $\bar{p}$ equals the consumers' reservation price. The price distribution does not have any mass points because otherwise the prices offered would not be profit-maximizing. This follows from the assumption that $\lambda_1 > 0$. If $\lambda_1 \to 0$, the outcome converges to the monopoly solution of Diamond (1971). Bontemps et al. (2000, pp. 317) show some implications of the equilibrium solution, particularly the influence of λ_1. If the rate at which actual customers receive other price offers increases, (large) firms with low prices will have an advantage and their customer base increases. Additionally, the profits of large firms increase and those of small firms with higher prices decrease. This means that the larger λ_1 is, the bigger are the differences in firm size and profit.

In conclusion, the model incorporates the following relationships. If it is assumed that there are heterogenous firms and homogeneous consumers who search sequentially for a low price, a stable price dispersed equilibrium arises because all consumers search, i. e. consumers search regardless of their status. Firms never offer a price above the consumers' reservation price. Equation (2.9) shows that according to the specified relationship between demand and price, large firms offer lower prices than small firms. Asymmetries in firm size and profits increase as actual customers' search activities increase.

In the next chapter, the simulation model, which is a synthesis of the evolutionary model of Winter (1984) and the above described search model of Bontemps et al. (2000) are presented. The results of the simulation and their relation to empirical data are given in Chapter 4.

A cynic might suspect that the lack of empirical work reflects a lack of interest in the real world on the part of those concerned with search rules. A glance at the authors ... suggests that this is not the only reason. It seems to me — and my interest in such matters is admittedly casual — that the problem of determining characteristics of search rules empirically is a very difficult one.

Rothschild (1974, p. 690)

Chapter 3

An Evolutionary Simulation Model With Price Search

3.1 Introduction

In this chapter, a new model is presented. It combines the modified search model of Bontemps et al. (2000) as presented in Section 2.3 with the evolutionary simulation model of Winter (1984). The combination results in an evolutionary simulation model in which the market price is not a single price, determined by equating aggregate supply with an aggregate demand function. Instead, each firm exhibits some monopoly power because consumers are not completely informed about sellers and the product prices. Each firm charges its own price, depending mainly on its size, cost structure, and on consumers' preferences and search costs. Consequently, the market is characterized by a non-degenerate price distribution.

The framework of the model presented in this chapter is the evolutionary simulation model of Winter (1984), which is based on joint work by Sidney Winter and Richard Nelson, summarized in Nelson and Winter (1982). The model of Winter (1984) itself is not outlined here in its original version. This is not necessary because it constitutes the frame of the hybrid model, i. e. the extension of Winter (1984) by the approach of Bontemps et al. (2000), which is described in detail.

The motivation to combine these two models is based on the following considerations. First, this combination allows to draw policy conclusions on consumer protection that also take dynamic effects on industrial development into account. Second, in the model of Bontemps et al. (2000), the phenomenon of dispersed prices is explained with different productivities of the firms, but it does not reveal the sources of these differences. On the contrary, Winter (1984) elucidates how firm differences arise by innovations, but there, firms are bounded to sell their products at a given market price. This assumption seems implausible, because the incentive to innovate fundamentally depends on the price-cost margin and, therefore, on the market power of a firm. Consequently, both models complement each other, for non-degenerate price distributions can often be observed and, if innovating, a firm is expected to be able to charge its desired price. Third, even if it seems to be unusual to implement an equilibrium model into an evolutionary simulation model, it should be kept in mind that Winter (1984) uses a neoclassical market model to establish a short run equilibrium. Furthermore, it is necessary that an equilibrium concept be used because such a simulation model always consists of two parts: a short run steady state, and transition rules that determine how the economy moves from one state to the next. Fourthly, innovations are a major determinant of economic growth, and it is shown in this thesis that consumers can influence innovative activities of firms and market structure. Therefore, this model extends the focus to one important question of industrial organization: what determines market structure. To sum up, combining both models offers the possibility of answering questions about the effects of the lack of information on behalf of the consumers, as well as the strategies of firms to exploit these frictions. It is demonstrated how the market structure develops with regard to the search costs, and how these search costs influence innovative activity, market concentration, and firm-size distribution. The simulation results also illustrate the different impacts of consumers' information on firms of different size and offer an explanation for how firm-size distributions arise. These and further simulation results are presented in Chapter 4.

3.2 The Model Structure

The main objective of Winter (1984) is to investigate Schumpeter's question of how innovations are generated. By analysing two distinct innovation regimes, the entrepreneurial and the routinized regime,[1] it is shown that both lead to different outcomes. In this study, only the entrepreneurial regime is of interest, where process innovations are understood as new technologies in contrast to improvements of technology in the case of the routinized regime. Fields of empirical application may be new markets, such as communication and information technology, with many small and medium sized firms competing and prices varying considerably. Besides the study of the innovation process, the central question addressed in the model presented here is how consumer behaviour affects firm behaviour and, therefore, market outcomes.

The Schumpeterian competition model of Winter (1984) can be described briefly as follows.[2] First of all, the industry is founded by one firm, a monopolist. In the subsequent periods, the industry develops through entries and exits occurring in each period due to general conditions in the industry and its history. All firms produce the same good but differ in productivity. To increase their productivity, firms engage in R&D to discover their competitors' technologies (imitation) and new technologies (process innovations). The most interesting feature of the model is that the market structure and the behaviour of the firms develop endogenously, depending on a firm's history and its environment. What can be observed is the time path of macro economic variables, such as output, level of technological knowledge, number of firms, as well as the time path of microeconomic variables, such as a firm's R&D policy, its R&D success, its market share, and its lifetime. After the market has developed for a certain time, the market structure usually settles so that there is a relatively constant number of firms in the market with some firms exiting and others entering the industry. Different results are obtained for the two innovation regimes, i. e. the market structure varies according to background conditions affecting the number and size of firms in the market.

[1]Further details are given in Subsection 3.2.10, p. 80.

[2]For further details, see Winter (1984) and Nelson and Winter (1982, part 5).

3.2.1 The Basic Structure

The model is constructed in discrete time, with time for technical reasons being interpreted so that one period is three months, i. e. a year consists of 4 periods. It is assumed that in each period t there is a finite number Z_t of single-product firms, all producing homogeneous goods.[3] To account for individual firm histories, the set of indices of active firms in period t is defined by $\mathcal{Z}_t$. For example $\mathcal{Z}_0 = \{1, \ldots, Z_0\}$ with the number of firms in the market in period t being given by the number of elements in $\mathcal{Z}_t$, for instance, $Z_0 = \#\mathcal{Z}_0$. For a firm i in period t the only input needed for production is capital K_{it}, which depreciates at a constant industry-wide rate δ per period. The firms differ in their size, measured in terms of capital stock, in their production techniques, and in their R&D policies. Differences in production techniques are reflected by the production costs c_{it}, which are constant per unit of output. For the production function for each firm i it is assumed that the output Q_{it} in period t is proportional to the capital stock:[4]

$$Q_{it} = A \cdot K_{it},$$

with A being constant productivity. Total supply of the industry in period t is then given by

$$Q_t = \sum_{i \in \mathcal{Z}_t} Q_{it}.$$

Production costs c_{it} of a firm i in period t are composed of the variable input costs γ_{it}, which are specific to each firm, the industry-wide return on capital ρ, and the depreciation rate δ, i. e. the production costs per unit capital of a firm i at time t can be written as[5]

$$c_{it} = A \cdot \gamma_{it} + \rho + \delta.$$

[3] It is convenient to additionally assume that the good is a service or perishable, so that it can only be consumed in the period of production.

[4] In the WINTER (1984) model the firms differ in their productivity but their production costs are identical. In the new model outlined here, firms have identical productivities but vary in production costs.

[5] Normally, these cost components cannot be summarized in this way because γ_{it} depends on the output, and ρ and δ are measured per unit capital. Here, it is possible as a simple linear production function is assumed.

As is explained in Section 3.2.4, the individual cost component γ_{it} can be influenced by efforts in R&D. In the industry, the variable input costs are distributed according to a cumulative density function $\Omega(\gamma)$. Total costs of a firm consist of the production costs plus expenditures on R&D.

Firm i's profits π_{it} in period t are defined as revenue minus costs, i. e.

$$\pi_{it} = P_{it} \cdot q_{it} - \gamma_{it} \cdot Q_{it} - (\rho + \delta) \cdot K_{it} - (r_{it}^m + r_{it}^n) \cdot K_{it},$$

where revenues depend on the sold amount q_{it} times the individual price P_{it} of firm i in period t. Costs depend on the firm's capital stock, and on the produced units Q_{it} of the good, which may differ from the sold units q_{it}, where $q_{it} \leq Q_{it}$. Total costs consist of the variable input costs, ρ and δ, and the expenditures on R&D, where r_{it}^m and r_{it}^n are the rates of imitative and innovative R&D expenditures per unit capital, governed by routines (decision rules). These are explained in Subsection 3.2.7.

The firms act in two stages. First, the technology is determined. In the second step, given technology and capital, firms' decide at which price they will offer their output. The success of a firm during its lifetime is measured by a variable called 'performance', X_{it}, and is defined as a moving average process of a firm's profits:[6]

$$X_{it} = \theta \cdot X_{i,t-1} + (1 - \theta) \cdot \pi_{it}, \qquad 0 < \theta < 1. \tag{3.1}$$

In order to determine the innovative potential of the industry, the expected value of production costs $E_\Omega[\gamma]$ moves to the left as latent knowledge L_t increases. Consequently, innovating firms have the possibility of discovering ("drawing") new technologies with lower production costs.

3.2.2 Consumer Behavior

In this subsection, the state variables for consumers are defined. There are $N_t = N \, \forall \, t$ consumers in the market, where E_t of them are customers of a certain supplier in period t and the others, U_t, are consumers who either did not manage to find any supplier or who went to a supplier that had already sold out or whose supplier

[6]For $X_{i,0} = 0$ we have $X_{it} = (1 - \theta) \cdot \sum_{j=0}^{t} \pi_{i,t-j}$, i. e. the performance is the sum of all past profits weighted by an industry-wide constant θ.

had just gone bankrupt. Both types of consumers (E and U) always search, but their search intensities differ. Consumers of type U search with intensity λ_{0t}, and currently satisfied consumers (type E) search with intensity λ_{1t}, where it is assumed that $\lambda_{1t} \leq \lambda_{0t}$.

Consumers are homogeneous. Their reservation price φ_t depends on the search intensities λ_{0t}, λ_{1t}, the income index[7] b_t, the price offer distribution $F_{P_t}(p)$, and the bankruptcy rate ζ_t. It is implicitly given by Proposition 2.1, p. 57, as

$$\varphi_t = b_t + (\lambda_{0t} - \lambda_{1t}) \int_{\underline{p}_t}^{\varphi_t} \frac{F_{P_t}(x^+)}{\zeta_t + \lambda_{1t} F_{P_t}(x^+)} \, dx, \tag{3.2}$$

where $\underline{p}_t$ is the lower bound of the support of $F_{P_t}(p)$.

Equation (3.2) implies that each consumer only accepts a price lower than or equal to his reservation price. A consumer of type E only changes his supplier if he receives a price offer strictly below its current one.

In the remainder it is assumed that the search intensities are constant, i. e. search costs do not vary over the course of time and thus, $\lambda_{it} = \lambda_i \, \forall \, t$ and $i = 0, 1$. The consumers are matched randomly to the firms, and each firm can be drawn with the same probability.[8] If matched to a firm, the consumer buys exactly one unit per period. He buys from this supplier until he receives an offer with a lower price or until the firm goes bankrupt.

This is the first aspect that differs from the original Winter (1984) model. By implementing Equation (3.2) into the model, a link between consumer *behaviour* and industry structure is established. Not only does the willingness to pay depend on income and search costs, it is also contingent on the prices offered and on the bankruptcy rate. In this way, consumers adjust their behaviour to the conditions on the supply side. On the contrary, in Winter (1984) there are no such limits for the prices. The constant elasticity of demand function involves the revenues in the industry always being the same.

[7]Later, it is assumed that $b_t = b \, \forall \, t$. Generally, it must hold that b exceeds the minimum total production cost to guarantee positive supply, i. e. Prob$[b > c_{it}] > 0$.

[8]Alternatively, one could assume that firms are matched with a probability that depends on their size, i. e. a large firm is more likely to be found by a consumer than a small one. This self-enforcing effect has been too strong in the simulation.

3.2.3 Determining the Price

In this new model, firms have to keep the demand side in mind, i. e. they can grow and expand their capital stock only if they (expect to) sell the quantity produced. On the contrary, in the model of WINTER (1984), the firms always sell the whole quantity they have produced and, thus, can grow irrespective of external factors. The only constraint is internal, i. e. they have to remain within their financial limits for investment.

In order to determine the price each firm charges for its output, the mechanism of BONTEMPS et al. (2000)[9] is applied. A firm reaches its profit maximum if it can sell all its produced units, i. e. if $q_{it} = Q_{it}$. The quantity Q_{it} that can be expected to be sold in period t by a firm charging price P_{it} is given by

$$Q_{it} = l(P_{it}) = \frac{E_t}{Z_t} \cdot \frac{d\,\bar{G}_{P_t}(P_{it})}{d\,\bar{F}_{P_t}(P_{it})} = \frac{E_t}{Z_t} \cdot \frac{1+\kappa_1}{[1+\kappa_1 F_{P_t}(P_{it})][1+\kappa_1 F_{P_t}(P_{it}^{+})]}, \qquad (3.3)$$

where $E_t \cdot \bar{G}_{P_t}(P_{it})$ is the number of consumers who pay a price above P_{it}, $Z_t \cdot \bar{F}_{P_t}(P_{it})$ is the number of firms that offer a price above P_{it}, and $\kappa_1 = \frac{\lambda_1}{\zeta_t}$. To ensure that the profit maximizing problem of the firm has a unique solution, it is required that $\Omega(\gamma)$ is continuous.

Since the output of a firm is determined by its capital stock, the relationship of Equation (3.3) is used inversely, i. e. from $Q_{it} = l(P_{it})$ follows $P_{it} = l^{-1}(Q_{it})$. The function $l(p)$ decreases in p and, therefore, a firm $i \neq j$ with $K_{it} < K_{jt}$ never charges a price below that of firm j. The relationship of Equation (3.3) indicates that a firm takes into consideration the consumers' behaviour (λ_1) as well as the behaviour of its competitors ($F_{P_t}(p)$, ζ). It also shows that a successful firm is rewarded by the consumers when offering a relatively low price. This is the second major difference to the model of WINTER (1984).

Instead of equalling aggregate demand and supply, a firm's price offer P_{it} is determined according to a search cost approach. This is reflected in Equations (3.2) and (3.3). These equations are substituting the assumption of WINTER (1984) that the consumers are characterized by a unit elastic aggregate demand curve. This is a very short description of consumers' behaviour. It is quite restrictive to assume that

[9] See Section 2.3, pp. 55.

consumers are perfectly informed. Furthermore, it neglects the influence consumers have on firms' behaviour and market outcomes. Not only is the replacement of the aggregate demand function by Equations (3.2) and (3.3) an exchange of functions, it is also a replacement of a simple theory by a more sophisticated one. Additionally, the bankruptcy rate, which is exogenous in the model of Bontemps et al. (2000), becomes endogenous. The price distribution may also vary over the course of time. Thus, changes on the supply side also have repercussions on consumers' behaviour.

Having so far defined the state variables of the industry and derived the price distribution, the status of the industry in a period t is fully characterized. Subsections 3.2.4 – 3.2.8 describe the transition rules, which define what the industry in period $t+1$ may look like, i. e. the probability distribution of the next industry state, given the industry state of period t and its history.

3.2.4 Change of Technology

As mentioned above, a firm can improve its technology, i. e. lower its production costs γ_{it} by imitating an existing technology of a competitor or by innovating. Both activities require R&D expenditures. The results of a firm's R&D process are stochastic and the expenditures on R&D are governed by routines. These routines are decision rules for the adjustment of R&D expenditures that take the firm's history into account. It is assumed that the behavioural rule is a simple satisficing mechanism.[10]

The value of $\gamma_{i,t+1}$ is determined by a two-stage random process. In the first stage it is analysed whether the activities induced by the R&D expenditures lead to any results at all. This is represented by independent random variables, d_{it}^m and d_{it}^n, which take the value 1 if there is an imitation or innovation "draw", or zero if there are no results.[11] The probability of receiving a draw is positively related to a firm's R&D expenditures:

$$\begin{aligned} \text{Prob}[d_{it}^m = 1] &= a^m \cdot r_{it}^m \cdot K_{it} \qquad \text{and} \\ \text{Prob}[d_{it}^n = 1] &= a^n \cdot r_{it}^n \cdot K_{it}, \end{aligned} \tag{3.4}$$

where a^m and a^n are positive parameters.

[10] Vosskamp (2000, p. 4) also discusses rules of thumb.

[11] The idea behind is a Poisson process governing the draws, see Winter (1984, p. 299).

In the second stage the outcomes of the draws are determined. This is done by drawing randomly a value γ_{it}^m from the distribution of (capital-weighted) production costs $\Omega_t(\gamma)$ in the industry at time t if firm i has an imitation draw ($d_{it}^m = 1$), and by drawing randomly a value γ_{it}^n from a distribution of technological opportunities, $\Omega_t^+(\gamma)$ if firm i has an innovation draw ($d_{it}^n = 1$). As innovating implies exploring new technologies, i. e. technologies which cause lower costs than those which are currently used for producing, for an innovation draw the adequate distribution is generated by lowering each period the mean of the distribution of production costs by the growth rate of latent knowledge, L_t. At last, the results of the draws have to be evaluated. In period $t+1$ firm i produces at cost $\gamma_{i,t+1}$, where

$$\gamma_{i,t+1} = \min\{\gamma_{it}, \gamma_{it}^m, \gamma_{it}^n\}, \tag{3.5}$$

i. e. the firm produces with the best available technology.

Expenditures on innovative activity are only beneficial if the firm can expect a certain profit from an innovation. This is ensured by assuming that an innovative technology cannot be imitated immediately. Instead, it is revealed to other firms so that in the first period, the innovation is "invisible", and, in subsequent periods, it is revealed gradually, so that after some periods the patent protection vanishes. The risk of being imitated depends on the firm size. As the imitation draws are taken from the distribution of *capital-weighted* production technologies, the probability for a large firm to be imitated is higher than for a small firm. Thus, the expected benefits of an innovation increase if the size of the innovating firm decreases.

3.2.5 Investment

The capital stock determines output and is thus an important strategic variable for the firm. Due to depreciation, the capital stock shrinks each period at an industry-wide constant rate δ. To keep its position (market share), the firm has to invest in its capital stock. The capital stock of the next period is determined by the investment equation

$$K_{i,t+1} = I_{it}\left(\pi_{it}, \frac{q_{it}}{Q_{it}}, K_{it}, \frac{\lambda_0(N-E_t)}{\#\mathcal{Z}_t}, \delta\right) \cdot K_{it} + (1-\delta) \cdot K_{it}.$$

The investment function $I_{it}(\cdot)$ gives gross investment per unit capital. It depends positively on the profits π_{it}, the ratio of sold to produced units, $\frac{q_{it}}{Q_{it}}$, the expected new customers $\frac{\lambda_0(N-E_t)}{\#\mathcal{Z}_t}$, and the depreciation rate δ. Investment depends negatively on the size K_{it} of the firm.

Desired investment $I_{D_{it}}$ is larger for successful firms but decreases in firm size. It should be noted that I_{it} is only investment per unit capital. Thus, large firms will normally invest more money than small firms in absolute numbers. Whether a firm can invest as much as it desires depends on its financial possibilities. From below, investment is bounded by zero, and the upper bound depends on the interest rate as well as a firm's profits.[12] If profits are positive, a firm's financial possibilities are better than with negative profits. Analogous to WINTER (1984, p. 319), investment within the financial limit is calculated as

$$I_{F_{it}} = \begin{cases} \delta + 3 \cdot \frac{\pi_{it}}{K_{it}} & \text{for} \quad \pi_{it} > 0 \\ \delta + \frac{\pi_{it}}{K_{it}} & \text{for} \quad \pi_{it} \leq 0. \end{cases} \tag{3.6}$$

Gross investment per unit capital for firm i in period t is then given as

$$I_{it} = \max \left\{ 0, \min\{I_{D_{it}}, I_{F_{it}}\} \right\} .$$

3.2.6 Exit

Firms may exit the market for two reasons. First, the capital stock may shrink below a minimum level necessary for production (minimum efficient scale). This could also be interpreted as financial restriction.[13] The other reason is that the performance variable X_{it} falls below a critical value. It is required that in the short run, a firm should be able to cover at least its variable production costs γ_{it}. Hence, the critical value of performance is given by $-(\rho + \delta + r_{it}^m + r_{it}^n)$. Otherwise, the rates of return on capital are too low, which is caused by R&D expenditures having been too low. In the model presented here, there are additional circumstances which may cause

[12] In the WINTER (1984) model the limes of gross investment is equal to δ if market share and profits tend towards zero, i. e. in the limiting case of perfect competition the capital stock remains constant.

[13] See VOSSKAMP (2000, p. 5).

an exit. A firm may have bad luck over a longer time period and rarely sell all of its produced goods. Since this is reflected in a reduction of profits, this exit condition is covered by the performance measure X_{it}. It is also included in the first exit condition because desired investment is negatively affected by bad sales and, thus, the capital stock may shrink. A further cause of exit results from profitability. If the production costs are too high compared to the reservation price of the consumers, a firm has to exit the market, i. e. if in the long run $\varphi_t \leq P_{it} < c_{it}$. The sole condition that $P_{it} < c_{it}$ is not sufficient for exit because the firm can always try to sell its products in the short run at $\varphi_t \geq P_{it} = \gamma_{it}$. Thus, a firm has to exit if $P_{it} < \gamma_{it}$, i. e. if variable production costs are not covered by the price.

The number of exiting firms may vary from period to period. The proportion of exiting firms to the total number of firms Z_t is measured by the (endogenous) variable ζ_t, which itself is a determinant of the consumers' reservation price φ_{t+1}.

If a firm goes bankrupt, it exits the market, and loses its capital stock. Its customers have to start searching from anew. Hence, the next price which they will accept is any price below their reservation price, and maybe larger than the one previously paid. In the short run, the proportion of potential consumers increases. In consequence, the remaining firms can expect more randomly matched customers. Additionally, they have the chance of increasing their customer base, which makes further expansion possible.

Note that since the model is stochastic, the success of a firm depends to some extent on its luck in two different ways. Without any imitation or innovation draw, the firm's technology becomes outdated after a while and in the long run the firm may exit. The second random component are a firm's sales. Since a firm can only form expectations of the quantity demanded (on which its production decision is based), three possible states can occur. First, the number of customers fits exactly the quantity produced; second, the firm still has some units left over; thirdly, there are more customers than products produced. The first and the third state do not cause any problems, at least for the firms. On the contrary, the second state is dangerous if occurring over a longer sequence of periods. This is because the firm had produced a stock which it did not sell completely. As it is assumed that the goods are perishable, the firm incurs costs of production but has no income for it,

i. e. the profits are affected negatively by unsold stocks.[14] As a result, the firm will be doomed to exit.

3.2.7 Policy Adjustment

The firm's expenditures on R&D, r_{it}^m and r_{it}^n, have a decisive influence on its success. If a firm is successful, there is no need to change its R&D policy. If a firm is less successful than the average, it may wish to change its policy. Expenditures on R&D are modified according to a satisficing and random search mechanism. As in Winter (1984), the aspiration level is defined as follows: performance X_t should be at least as high as the capital-weighted average profits $\bar{\pi}_t$ of the industry in period t. That is, a firm has no incentive to change its policy as long as its performance is above average. If a firm has an unsatisfactory performance, it will adjust its policies incrementally to the average policy of the industry with probability $h_r > 0$. With probability $1 - h_r$, the adjustment process is postponed to a later period. Since the observation of the average industry policy $\bar{r}_t^m$ ($\bar{r}_t^n$) may be subject to some errors, it is modified by an identically and independently distributed random disturbance u_{it}^m (u_{it}^n), drawn from a normal distribution with mean zero, standard deviation σ^m (σ^n) and truncated to the left at zero.

R&D expenditures of the next period are then determined by the decision rule

$$r_{i,t+1}^m = \begin{cases} r_{it}^m & \text{for } X_{it} \geq \bar{\pi}_t, \\ (1-\beta)r_{it}^m + \beta\bar{r}_t^m + u_{it}^m & \text{for } X_{it} < \bar{\pi}_t, \end{cases} \tag{3.7}$$

$$r_{i,t+1}^n = \begin{cases} r_{it}^n & \text{for } X_{it} \geq \bar{\pi}_t, \\ (1-\beta)r_{it}^n + \beta\bar{r}_t^n + u_{it}^n & \text{for } X_{it} < \bar{\pi}_t, \end{cases} \tag{3.8}$$

where the bar indicates a capital-weighted industry average and β is the adjustment factor towards industry average, with $0 < \beta < 1$.

To prevent the firm from changing its policy each period, a policy is held constant for some periods. This can be justified because usually, a new policy takes effect with a certain time lag.

[14] One could also imagine that the firm has additional costs of destroying the product.

3.2.8 Entry

To generate a basis for entry, it is assumed that there is a certain level of 'background' R&D activity performed by institutions which are not funded by the industry itself. These external R&D expenditures are equally divided between imitative and innovative activities, and they also generate profitable production techniques.

The imitative and innovative results are draws out of Poisson distributions depending on the level of the external R&D expenditures. Their means B_t^m and B_t^n are given by

$$B_t^m = a^m \cdot R^m \qquad \text{and} \qquad B_t^n = a^n \cdot R^n,$$

where a^m and a^n are positive parameters (see Equation (3.4)), and R^m and R^n are the external expenditures on imitative and innovative efforts. A draw from these distributions gives the number of potential imitative and innovative entrants.

The technology of an entrant, γ_e, is determined by either a draw from the distribution of (capital-weighted) production costs $\Omega_t(\gamma)$ (given an imitative draw) or from the distribution of production opportunities, $\Omega_t^+(\gamma)$ (given an innovative draw), as described in Section 3.2.4, pp. 74.

Further firm characteristics are chosen randomly from the according distributions. R&D policies of an entrant are set equal to the capital-weighted industry means.

In order to evaluate the profitability of entry, the expected profits are calculated. Entering is worthwhile if expected revenue minus production costs exceeds an entry barrier rate r^e. This reflects the level of R&D expenditures that are necessary to maintain the chance to survive.[15] Because of a lack of reliable information, the entry barrier rate is disturbed by a normal random variable u_{it}^e with mean zero, standard deviation σ_e, and truncated to the left at zero. A firm will enter the market in $t+1$ if

$$A \cdot (P_{i,t+1} - \gamma_{i,t+1}) - \rho - \delta > r^e + u_{it}^e.$$

A firm that enters with an innovative technology is protected from being imitated by starting with a small size relative to the market size as well as by having the same patent protection as incumbents do.

[15]In the WINTER (1984) model r^e equals the founder's policies, i. e. $r^e = r_{i,1}^m + r_{i,1}^n$.

3.2.9 Industry Birth

Industry birth takes place by the entry of an innovative firm. Additional firms will enter the market gradually. In the model that is extended by price search, this procedure is not appropriate. Instead, it is assumed that several firms are already in the market. Otherwise it would hardly be possible to assume distributions of prices and costs. This is due to the underlying idea of search cost theory, which is in sharp contrast to perfect competition, namely that it is possible to study questions of market power in an atomistic market.[16] Holding the assumption that consumers search, there is no need for a model of oligopolistic competition to show that prices are above marginal costs, because each firm has its local monopoly power. Furthermore, consumer search would not be a topic of interest if the number of firms was small.[17]

3.2.10 Innovation Regimes

In Winter (1984), a distinction is made between two innovation regimes: the entrepreneurial and the routinized regime which refer to the early and late work by Schumpeter, respectively. In his book "Theorie der wirtschaftlichen Entwicklung", Schumpeter (1911) develops the idea that innovation mainly originates in small enterprises, with a formative influence of the innovative owner, the entrepreneur. Later, in "Capitalism, Socialism, and Democracy", Schumpeter (1943) maintains that large firms also contribute to innovation processes by gradually improving their production techniques, which is called incremental innovation. In reality, both types of innovations can be observed in the same market, but in the simulation model a distinction has to be made between the two regimes because some parameters of the model must have different values, depending on what type of innovation is studied.[18] The entrepreneurial regime is characterized by a high degree of external

[16] The only exception concerning standard textbook models is monopolistic competition. This is, however, of no empirical relevance, see e. g. Wied-Nebbeling (1997, p. 104).

[17] Recall that in statistics the number 30 is a large number.

[18] This mainly concerns the values of the external expenditures on innovative efforts, R^n, and a^n, a positive parameter governing the innovation draws, which are inversely related in the two regimes.

innovative efforts, but there are hardly any usable results. Since an innovation improves the existing technology only incrementally, for a firm it is important that many innovative draws be made. Consequently, market entry becomes more difficult the older the industry is because large firms are dominating the market and smaller firms can hardly survive.

Thus Senator Douglas ... asserted, unfortunately without explanation, that a competitive market would exist if 'only' 10 per cent of the consumers were 'cost conscious'.

Wilde and Schwartz (1979, p. 543)

Chapter 4

Simulation and Results

4.1 Introduction

In this chapter, the design of the simulation is described and the simulation results are presented and discussed. The simulation model is based on the theory outlined in Section 2.3 and Chapter 3.

Before the simulation results are presented, it would be appropriate to make some comments concerning the structure of the simulation model in comparison to the theoretical model. The specification and calibration are briefly described in Section 4.2. In Section 4.3, the data are presented, interpreted, and conclusions are drawn. Section 4.4 summarizes the analysis of the simulation results.

This chapter offers insights into the influence of consumer behaviour on economic change. First, it is shown how firm characteristics depend on the search intensities of potential consumers and active customers. It turns out that in general the activities of potential consumers affect the level of the capital stock, profits, and investment, whereas the activities of actual customers influence the variance between firms. Concerning expenditures on R&D, it is shown that active consumers play the key role with respect to the level of R&D expenditures as well as the outcome of the research process. It is worthwhile considering that if firms are confronted with intensively searching active customers, they spend more on R&D, but observe fewer improvements of technologies than if active customers search only little. In the second part, the effect of search on the price distribution is analysed. In the short run, the price level depends positively on the search intensity of potential consumers, whereas, in the long run, a high search intensity of actual customers lowers the price level. Third, the impact on the market structure is described. It turns out that a high search intensity of the actual customers increases the concentration of firms and the bankruptcy rate. Finally, some policy options are outlined.

With respect to the cross-sectional regularities found in empirical studies (and outlined below), it will be shown how the model reflects these stylized facts and explains the findings by making use of a new approach, i. e. the extension of an evolutionary approach by demand conditions where the consumers have to search for opportunities. KLEPPER (1996) summarizes a multitude of empirical studies concerning the evolution of market characteristics. An evolutionary pattern, that describes the key features of a maturing industry (from the creation of the market by a product innovation up to the decline of the industry), is the life-cycle. In the beginning of a life cycle, competition concentrates on *product* innovations because of demand uncertainties, i. e. firms have to learn about consumers' preferences. The learning process leads to the emergence of a dominant design to which the industry becomes locked-in. Afterwards, *process* innovations become the most important factor to secure efficient production.

KLEPPER (1996, pp. 564) formulates three stylized facts dealing with process innovation. The first stylized fact implies that the number of entries in a new market may first increase and is expected to decrease over the course of time. Second, the number of firms is expected to increase, and after reaching its peak it is expected to decrease. Thirdly, turbulence in the market shares of the large firms decreases so that the leaders are established in an early state. One should keep in mind that the studies focus on technologically progressive industries and also consider subsequent product innovations.[1] For relatively homogeneous products, the pattern of the life cycle must not necessarily be observed. It will be shown that the simulation model reproduces most of these stylized facts.

MAZZUCATO (2000, p. 7) also summarizes evidence for the life-cycle hypothesis in many industries. In the first phase, market shares are instable and competition is

[1]The model presented by KLEPPER (1996) leads to an advantage of firm size with respect to R&D. Although empirical studies found a close relationship between R&D and firm size, the general existence of advantages of size is discussed controversially.

high. Later on, market shares are relatively stable and firms are more concentrated. As further stylized facts she adds the asymmetry of firm-size distributions, the persistence of production techniques and, therefore, of costs and profitabilities, and differences in innovation capabilities.[2]

It goes without saying in empirical economics that firms are heterogeneous, which has, however, not yet been integrated into most microeconomic theories. Instead, the notion of the representative firm is still dominating.[3] The special issue of *Industrial and Corporate Change*, 1997, Vol. 6(1) contains a pool of papers concerning firm heterogeneity. In these contributions it seems to be accepted as a stylized fact that the differences, for instance, in profits and innovative activity, are persistent in the way that profits do not converge to a single value and innovations are autocorrelated. Furthermore, for many industries it is shown that the firm-size distribution is equal or at least similar to a skewed distribution, such as the Pareto or the log-normal distribution.[4] SCHMALENSEE (1989) describes as stylized facts that there are persistent differences in firms' profits and that the differences in profitability are mainly induced by firm-specific characteristics. These topics are analysed in detail concerning the data generated by the simulation model.

4.2 Specification of the Simulation Model

Before a simulation model can be run, the parameter values and the initial values of some of the variables have to be specified, for instance, the number of firms, the initial capital stock, and policy parameters. WINTER (1984) solves this task by starting the model with the entrance of one firm into the market. After a while, other firms enter the market thus making it evolve. In the model constructed here, this procedure cannot be applied because several firms are necessary to allow for a

[2]A large collection of empirical studies that concern the relationship between R&D and productivity on the firm level as well as on the industry level is contained in GRILICHES (1998).

[3]See e.g. the microeconomic textbooks by MAS-COLELL et al. (1995), NICHOLSON (1995) or VARIAN (1990).

[4]For details, see DOSI et al. (1997), MALERBA and ORSENIGO (1997), AUDRETSCH (1997), JENSEN and MCGUCKIN (1997), and SUTTON (1997).

non-degenerate price distribution. Therefore, a process similar to VOSSKAMP (2000) has been applied to calibrate the simulation model. This procedure works as follows.

The simulation is divided into two parts. To calibrate the model, a 'short' version of the model is run. The major parts, which account for the model dynamics, are excluded, namely the innovation process and capital accumulation. Hereby, firm-size distributions and price distributions are obtained. After 30 periods, an equilibrium is usually reached. The values obtained in the last period are taken as initial values for the complete model run.

In order to analyse the impact of different search intensities on the evolution of the market, the only parameters that are varied are the search intensities λ_0 and λ_1. Here, λ_0 is the search intensity of potential consumers, i. e. those consumers who intend to purchase the good, but who either have not found a supplier so far or who do not currently have a supplier because their former supplier has gone bankrupt. λ_1 reflects the search intensity of actual customers, i. e. those consumers who are currently matched to a supplier. As it does not make sense to run the model for all possible combinations of the two parameters, four cases are chosen (see Table 4.1 below). For each combination of λ_0 and λ_1 one set of initial values is generated. Each configuration of search costs then is run 100 times with varying random numbers.[5] Depending on the initial value of the random number generator, the results will vary even for the same initial parameter and variable values. Using the same initial values (except for the random numbers) ensures the comparability of the different model runs. Random numbers play a role, for instance, in determining the value of an imitation or innovation or the number of entrants. By fixing the initial value of the random number generator, each run can be reproduced.

Note that in the presentation a distinction is made between single runs which are sometimes used as examples, and the average of 100 runs with identical parameter values but different random numbers. The averages are calculated because the results of single runs depend on the choice of the random numbers and generate different histories. Averaging a large number of runs takes this phenomenon into account and ensures that the outcome observed is free from random effects. Analogous to WINTER (1984), 100 periods correspond to 25 years. This is quite a long

[5]The number of 100 runs is enough to level out the random effects occurring in single runs.

span of time to observe an artificial economy, where only the direct environment of the firms changes, but the general set-up remains the same.

Since the simulations generated a great wealth of data it is neither possible nor necessary to report all the details. Instead, those variables and relationships are presented which are of major interest for this study. The presentation is restricted to the four different constellations of search costs shown in Table 4.1: low search costs tend to drive the economy towards competitive outcomes, i. e. average prices should tend to the competitive price because with low search costs consumers are almost perfectly informed (case I). The medium case represents the situation where some consumers are well-informed and others are not (case II). The case of high search costs represents the tendency towards monopoly prices because the consumers are badly informed and may be exploited by the suppliers to a certain extent (case III). In order to generate a contrast, a run with high λ_0 and low λ_1 was performed (case IV). It will be demonstrated below that λ_1 plays a more important role than λ_0 in characterizing the market structure, which was predicted by MORTENSEN and NEUMANN (1988).

Table 4.1: Constellations of Parameters

Parameters / Case	λ_0	λ_1
Case I	0.4	0.2
Case II	0.6	0.4
Case III	0.8	0.6
Case IV	0.8	0.2

The only parameters that are varied between the four cases are the search intensities[6] λ_0 and λ_1. The basic idea for the grouping of cases is based on the economic theory following MORTENSEN and NEUMANN (1988), that λ_1 is the decisive parameter for determining the market structure. For the difference between the search intensities of potential consumers and actual customers as standard case $\lambda_0 - \lambda_1 = 0.2$ is chosen. A fourth case is constructed to find out for what effects λ_0 and λ_1 account. In this case, the search intensity of potential consumers equals the highest value of

[6]Remember that a high search intensity indicates low search costs and vice versa.

the standard cases ($\lambda_0 = 0.8$) and the search intensity of actual customers equals the lowest value used in the standard cases ($\lambda_1 = 0.2$). This means, that it is possible to differentiate whether a certain observed phenomenon is mainly affected by the search activities of the potential consumers, λ_0, or the search activities of the actual customers, λ_1.

Details of all the parameter values and the initial values of the variables as well as the programme code of the model are available in Appendix B and Appendix C, respectively. The initial values are mainly taken from Winter (1984).

4.3 Simulation Results

In this section, the data of the simulation are presented. Explanations of typical patterns are given, and the data are visualized in figures and summarized in tables. The presentation is divided into three parts. Part 1 contains firm-specific data. Part 2 refers to price distributions. An analysis of the market structure is given in part 3. In Section 4.4, the results are summarized.

The history of an industry is characterized by the development of the firms, the prices, and the market structure. The results depend on the extent of search costs. Firms are characterized by (the development of) their capital stock, output, price, number of customers, profit, performance, their R&D policy and success, and their investment. Market structure is reflected by different measures: the number of firms, the frequency of entries and exits, the lifetime of firms, the concentration of firms, and a stability index that shows the intensity of competition regardless of the extent of concentration.

The data are presented for the four constellations of λ_0 and λ_1 mentioned above. If necessary, the time series have also been divided into three phases of the market process. The first phase is one of orientation (the early market phase), the second is the phase of consolidation and satiation, and the last one refers to the phase of the decline of the industry.

The majority of the data presented are means. To avoid random effects, for each combination of search costs 100 runs have been performed. For instance, the average capital stock is calculated as the mean of the capital stocks of all firms existing in period t for all 100 runs. In the graphical presentation, the mean is usually compared to the "best practice", i. e. for each period the values of the best firm in the according period are plotted (maximum). Additionally to the mean and the maximum, the minimum and the standard deviation are given. Therefore, it can easily be verified that although the initial conditions for firms are identical, they will differ in many respects after some time has passed, i. e. they are becoming heterogeneous. The degree of heterogeneity is represented by the standard deviation.

4.3.1 Firm Characteristics

In this subsection the characteristics of firms are studied. First and most important, the development of capital stocks is analysed. This includes presenting the average capital stock and its variability, the growth rates of capital stocks in the industry and, finally, the growth rates according to different firm sizes. Second, the development of investment is described. Third, attention is given to the development of profits and performance, and fourth to R&D expenditures and their effects on imitation and innovation. Point five concerns the development of the production costs. Finally, the relationship between the quantity supplied and the number of customers is analysed.

Capital

The analysis of capital first shows that firms are larger on average, for more potential consumers enter the market. Besides, if the search intensity of the actual customers is high, firms are more heterogeneous than if this search intensity is low. Concerning the growth of firms, it can be observed that the growth rates are negatively correlated with the firm size, i. e. small firms grow faster than large firms.

In Figure 4.1, the solid line shows the development of the average capital stock of firms (mean) for the different search intensities (cases I – IV). The dashed lines describe the minimum and maximum capital stocks observed in each period (min/max). The dotted lines represent the variation among firms in terms of the standard deviation (std).

Concerning the first three cases, it can be noted that in the first two market phases there is an increase in the average capital stock, and in the third market phase it

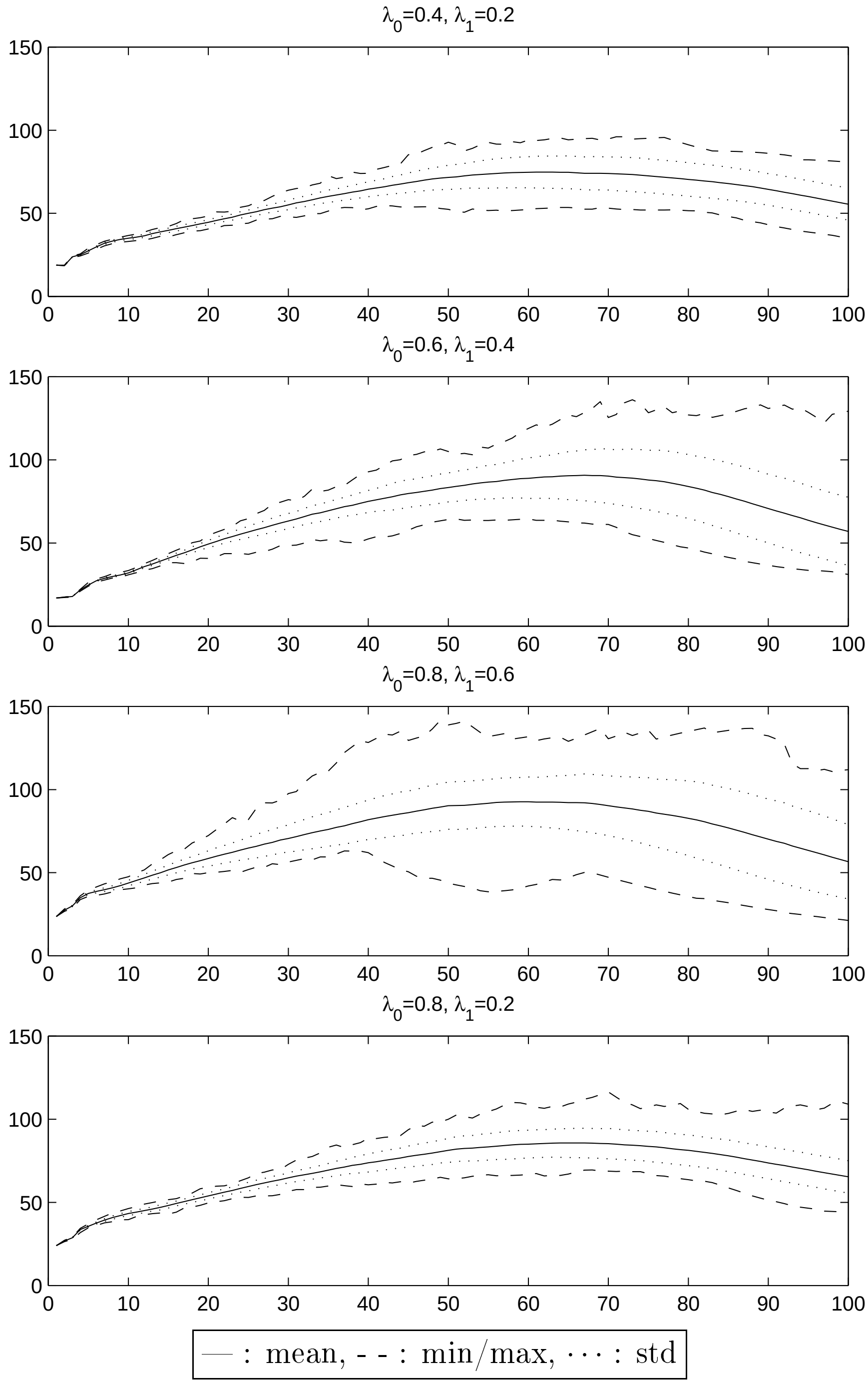


Figure 4.1: Average Capital Stock

decreases. The increase and the decrease of the average capital stock are larger for high search intensities. The mean of the average capital stock is also larger for high search intensities, namely, case I (59.4927) $<$ case II (67.8050) $<$ case III (72.5562). At the end of the run ($t = 100$), the average capital stocks are very similar in all three cases: case I (55.4741), case II (57.0172) and case III (56.5661). In addition, the higher search intensities account for larger standard deviations in the cases I – III.

The fourth plot offers some insights into the different effects of λ_0 and λ_1. It shows that the results concerning the average capital stock depend strongly on λ_0. The mean of the average capital stocks in case IV is 69.0835. At the end of the run, it amounts to 65.3588. The standard deviation is relatively low like the standard deviation in case I, whereas the maxima in particular show a slightly larger variability than in case I. The standard deviation of case IV is clearly less than those of the cases II and III. The increase in the average capital stock during phases I and II is almost as large as in cases II and III, i. e. is more distinct than in case I. Since the decrease in phase III is very slow, at the end the average capital stock of case IV is the largest of all four cases.

The general pattern of the development of the average capital stock is similar in all four cases, but it differs with respect to the level and variability. The search intensities λ_0 and λ_1 cause different effects. Comparing case I ($\lambda_0 = 0.4$; $\lambda_1 = 0.2$) with case IV ($\lambda_0 = 0.8$; $\lambda_1 = 0.2$), it can be noted that with a higher search intensity of potential consumers, λ_0, the average capital stock increases, and the increase of the average capital stock during the first two market phases is more distinct than in cases II and III, whereas the slope of the decrease in case IV is almost as gentle as in case I. The search intensity of actual customers, λ_1, influences the standard deviation. The higher their search activity, the more divergence between firms can be observed.

Before conclusions about the market structure are drawn, some comments on the effects of search intensities should be made. At the first glance, highly active potential consumers favor large firms with a tendency towards a uniform distribution of firms if λ_1 is low. This could be explained by the random effect of λ_0. High activity by potential consumers means that each firm can expect many customers regardless of the price it offers. High search activities of actual customers, λ_1, has a contrary effect. As a high λ_1 stands for price attentive customers, firms which offer a low price are blessed with many customers switching from suppliers with higher prices (with the prospect that they remain loyal). As a result, some successful firms grow large and many others remain relatively small, what is indicated by a higher standard deviation in cases II and III than in cases I and IV with a lower λ_1.

To sum up, it can be noted that the market structure that may emerge in this simulation model will be described by a diversity of firm sizes. DAS et al. (1993) suggest that the reason why small firms can co-exist with large firms in the same market is that small firms exhibit a higher production flexibility than large firms. They also report that this hypothesis is sustained by empirical data for the period 1970–1980 in another study.

In Figure 4.1, only data concerning the average capital stock are shown. The standard deviation indicates that not all firms are of the same size. Though starting with similar values, each firm develops distinctively. When ending up with different sizes, the firms must grow at different rates. The question arises whether there is a general pattern which the growth process of the firms follows. An early study concerning firms' growth is GIBRAT (1931).[7] He formulated the hypothesis, known as Gibrat's "Law of Proportionate Growth", that firms grow regardless of their sizes, i. e. a firm's size is given by

$$k_{it} = \alpha + \beta_i \cdot k_{i,t-1} + \varepsilon_{it},$$

where k_{it} is the log size of firm i at time t measured by the capital stock, α is the industry-wide growth rate of all firms, and ε is an identically and independently random variable. If the coefficient of autocorrelation, $\beta_i = 1\,\forall\, i$ then Gibrat's Law holds, i. e. the growth rate of firms follows a random walk (the growth process has a unit root).

Whether a variable follows a random walk is usually tested by applying the Dickey-Fuller test for unit roots.[8] The null hypothesis is $H_0 : \beta_i = 1\,\forall\, i$. To test for the presence of unit roots in univariate time series data, FULLER (1976) and DICKEY

[7]A recent survey on empirical and theoretical findings initiated by GIBRAT (1931) is given by SUTTON (1997).

[8]For details, see e. g. GREENE (1993, pp. 563).

and FULLER (1979) considered t statistics of ordinary least squares regressions. If the underlying data-generating process is integrated (i. e. a random walk), the t statistics have non-standard distributions. FULLER (1976) presents selected critical values for the test. To perform the unit root test, only those firms are selected from the replications and parameter constellations which have existed in the market for the whole time. This is because they provide many observations and it cannot be assumed that the random walk behaviour depends on the length of a firm's lifetime. Table 4.2 summarizes the results of the test for unit roots.

Table 4.2: Random-walk Behavior of Firms' Growth Rates

Test[ab] / Case	$DF < -2.61$	$DF < -1.95$	$DF < -1.61$	Total[c]
Case I	0.0669	0.1923	0.2996	1887
Case II	0.0633	0.2874	0.4231	782
Case III	0.2007	0.4230	0.5667	343
Case IV	0	0.0626	0.1900	1672

[a] DF stands for the Dickey-Fuller test statistic under the $H_0 : \beta = 1$. The critical values -2.61, -1.95, and -1.61 correspond to significance levels at 99%, 95%, and 90% for a test regression without constant and trend. It is presumed for the simulated data that the growth of a firm does not contain any drift or trend.
[b] The numbers in the first three columns are the proportions of firms with a test statistic below the critical value.
[c] Number of total time series considered for the unit root test. This is calculated as $\sum_{j=1}^{100} \sum_{i=1}^{150} I_{\{100\}} f_{ji}$, where f_{ji} is the number of periods firm i existed in the jth run and $I_{\{A\}}(x)$ is an indicator function.

The first three columns in Table 4.2 contain the proportion of firms for which the null hypothesis $H_0 : \beta = 1$ has been rejected, i. e. those firms which have a Dickey-Fuller (DF) test statistic below the critical value. The total number of firms included in the test are those that survived 100 periods. They are reported in the fourth column. The null hypothesis is rejected if the value of the DF statistic of a firm is smaller than the corresponding critical value (-2.61, -1.95, and -1.61, corresponding to a significance level of 99, 95, and 90 per cent). If the growth behaviour of firms in a certain market is a random walk, the percentage of rejection of the null hypothesis should amount approximately to 1, 5, and 10 per cent, respectively. The values in Table 4.2 all exceed the 1, 5, and 10 per cent level. The only case that shows a slight tendency towards a random walk is case IV. This is due to the strong random effect caused by the big difference between λ_0 and λ_1.

Before these results are interpreted, it is worthwhile contemplating some factors which influence the growth of firms in the market. There are two types of factors. The first type causes the growth of firms to be a random walk, whereas the second type leads to quite stationary behaviour. The (assumption of) randomness of the search behaviour of potential consumers is a type one factor. Given λ_1, the higher λ_0, the more probable it is that the growth rate of firms is a random walk. This can be seen by comparing case I ($\lambda_0 = 0.4$; $\lambda_1 = 0.2$) with case IV ($\lambda_0 = 0.8$; $\lambda_1 = 0.2$). There, for equal λ_1 case IV has proportions near the level where H_0 could be accepted, whereas in case I the proportion of test statistics for which the H_0 has to be rejected is quite larger. On the other hand, high search intensities of active consumers seeking for a lower price involves stationary growth rates. This is because a successful firm with lower prices is very likely to be successful in the next period. Given λ_0, the probability that the growth of firms is stationary increases in λ_1. This can be seen by comparing case III ($\lambda_0 = 0.8$; $\lambda_1 = 0.6$) with case IV ($\lambda_0 = 0.8$; $\lambda_1 = 0.2$). Here, for equal λ_0 the probability of stationary growth rates is higher in case III where λ_1 is larger. If λ_0 and λ_1 increase at the same time, the effect will not be clear. Nevertheless, one can conclude that λ_1 plays a more important role than λ_0 does regarding the growth behaviour of firms. This is evident if comparing cases I, II, and III, where the growth of firms becomes more and more stationary as λ_0 and λ_1 increase by the same absolute number.

Generally, it can be concluded that the growth behaviour of firms is neither stationary nor non-stationary. As the results show, firms' growth rates depend on the characteristics of the market under consideration. If the cases I, II, and III are considered as normal (in contrast to case IV), the result of the simulation can be summarized in the way that the growth behaviour of firms is rather stationary than non-stationary. Thus, the simulation does not provide evidence for supporting Gibrat's "Law of Proportionate Growth".

Another question that arises is if there are differences in firm growth in relation to firm size. It will be checked in particular whether different search intensities affect the growth rate of firms and whether there are different effects on firms of different size. In order to show these effects, the firms are divided into three groups with respect to their size in each period. The results are given in Table 4.3.

Table 4.3: Growth Rates, Firm Size, and Search Costs

Firms[a]	Small		Medium		Large	
Case	mean	std	mean	std	mean	std
Case I	0.0236	0.0604	0.0126	0.0379	0.0084	0.0330
Case II	0.0317	0.0615	0.0125	0.0412	0.0099	0.0388
Case III	0.0369	0.0598	0.0086	0.0372	0.0050	0.0376
Case IV	0.0320	0.0570	0.0119	0.0314	0.0069	0.0301

[a]For simplicity, to distinguish between small, medium and large firms, the total number of firms has been equally divided into three parts.

The average growth rate of the capital stock is negatively correlated with the firm size in all cases: 0.0236 (small), 0.0126 (medium), 0.0084 (large) for case I, 0.0317 (small), 0.0125 (medium), 0.0099 (large) for case II, 0.0369 (small), 0.0086 (medium), 0.0050 (large) for case III, and 0.0320 (small), 0.0119 (medium), 0.0069 (large) for case IV. This corresponds to the economic intuition that small firms grow faster than large firms. In general, the standard deviation decreases as the firm size increases. The decrease from small to medium-sized is quite large, whereas the standard deviation of the growth rates of medium-sized and large firms are similar, particularly for high λ_0. This indicates that small firms are more heterogenous in their growth rates than large firms.

Regarding small firms, the average growth rate of the capital stock is higher for high search intensities. This can be seen by the sequence 0.0236 (case I) $<$ 0.0317 (case II) $<$ 0.0369 (case III). If one looks at case IV, its mean of 0.0320 seems to be closest to that of case II. This pattern is less clear for medium-sized firms. With low search intensities (cases I and II), the average growth rates are the largest (0.0126 and 0.0125). In case III (0.0086) it is the smallest. Compared to case IV (0.0119), one can conclude that the growth rate of medium-sized firms is negatively related to the search intensity of the actual customers, λ_1. An effect of λ_0 is hardly visible. For large firms, a systematic influence can neither be detected for λ_0 nor for λ_1.

The influence of search intensities on the firms' growth rates differs among the three groups. With increasing search activity (from case I to case III), small firms grow faster, and medium-sized firms tend to grow less quickly. Large firms exhibit the mixed effect that the increase in search activity from case I to case II increases their growth, but a further increase in search activities (from case II to case III) decreases the growth rate below the initial level of case I.

If the growth rates of firms of different sizes are compared, small firms have the largest growth rates. Their growth rates are about twice as much as the growth rates of medium-sized firms, and more than three times higher than the growth rates of large firms.

Investment

The capital stock changes according to investment. In each period, the capital stock shrinks by a constant rate of depreciation. If the capital stock falls below its minimum efficient scale, the firm has to exit the market. As shown above, small firms grow faster than large firms, that is, small firms make larger investments relative to their size. It turns out that in absolute numbers, large firms invest more money, but the investment of small firms is larger per unit of capital. For all firms investment is higher for a high search intensity of the potential consumers. Differences between firms are bigger for intensively searching active customers.

The development of the average investment[9] is plotted as solid line in Figure 4.2. The dashed lines show the minima and maxima, and the dotted lines represent the standard deviation. During the first few periods there is a random increase and decrease in average investment in all four markets. However, this effect cannot be attributed clearly to the search intensities. This seems much more to be a two-stage adjustment process according to the low investment levels in period $t = 1$.

Concerning the further development of average investment, it becomes related to the search intensities of potential and actual consumers. First, it can be noted that the strength of the long wave, that occurs after the adjustment process, depends on λ_1. The flattest wave can be observed in cases I and IV, whereas in the markets II and

[9] The values shown are total investment, i. e. investment per unit of capital multiplied by the capital stock.

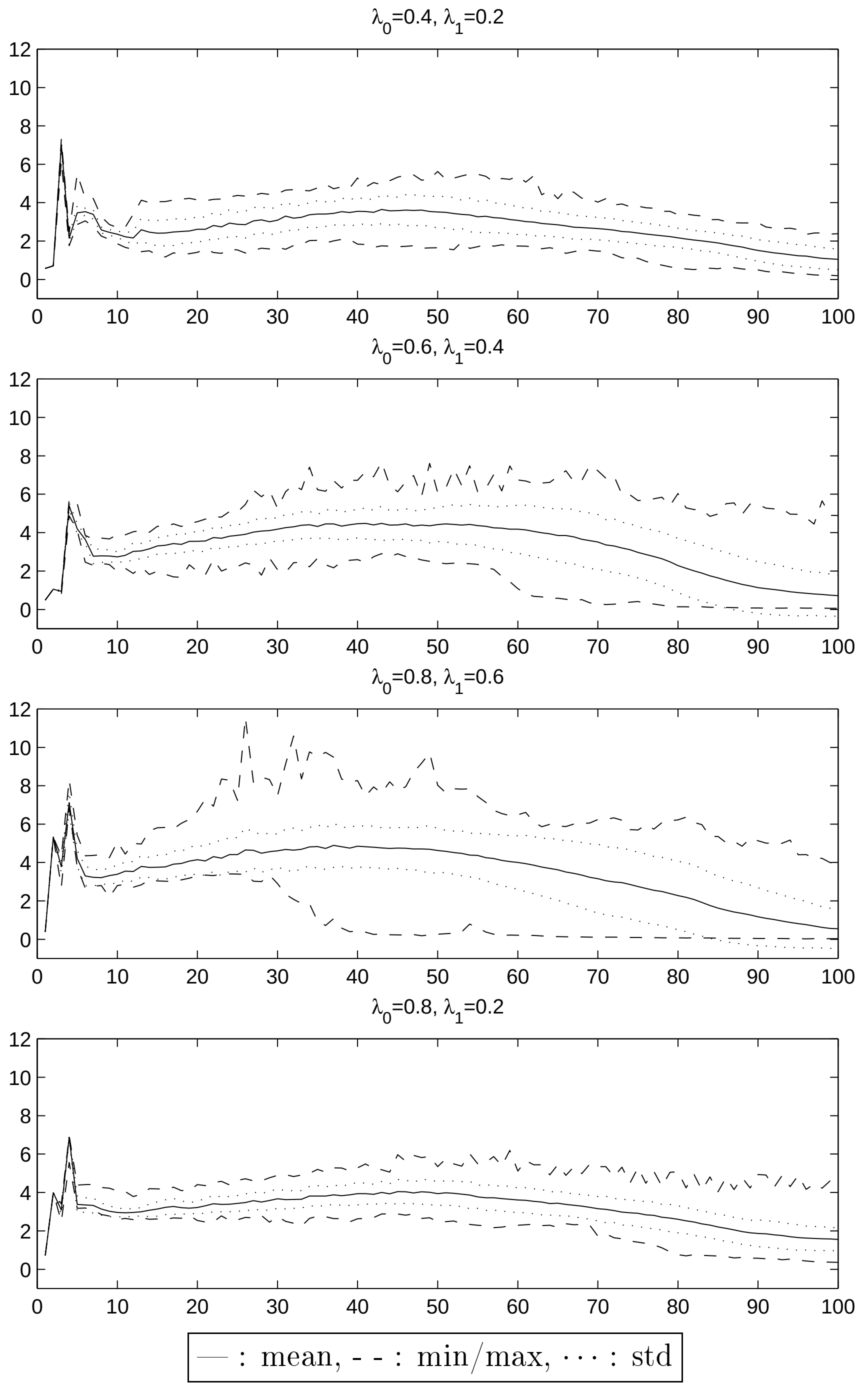


Figure 4.2: Average Investment

III the waves have a higher peak. On average, in the first three cases, firms invest more money the higher λ_0 and λ_1 are, so that case I (2.6705) $<$ case II (3.2164) $<$ case III (3.4474). Since the firms in case IV invest on average 3.1632 which is much more than in case I and almost as much as in case II, it seems that λ_1 has a strong influence on the average amount of money spent in each market.

The level reached in the last period is strongly negatively related to λ_1. The highest level occurs in case IV (1.5496) followed by case I (1.0480) $>$ case II (0.7130) $>$ case III (0.5453). One reason for this relationship may be that in the simulation model, investment per definition depends positively on profits and the sold units and negatively on the produced units. Investment also depends negatively on firm size so that for large firms investment per unit of capital is lower than for small firms. In absolute numbers, however, large firms invest more money than small firms, which makes, indubitably, an important distinction. One effect on investment stems from firms having more matching problems of demand and supply in markets with a high search intensity because of high fluctuations caused by λ_1 so that they often cannot sell their output completely. A big difference between sold and produced output keeps investment low because firms do not expect a large increase in demand for the next period. The second effect works into the opposite direction: a high λ_1 leads to a larger standard deviation and, therefore, to a spread in investment so that there are some large firms with high total investment forcing average investment up. Comparing case III ($\lambda_0 = 0.8$; $\lambda_1 = 0.6$) with case IV ($\lambda_0 = 0.8$; $\lambda_1 = 0.2$) with respect to the peak of the wave, the positive effect of λ_1 seems to dominate, whereas the value at the end of the run seems to be negatively affected by λ_1.

As expected, the standard deviation of the average investment increases in λ_1, i.e. it increases from case I to case III, and the standard deviation in case IV is approximately the same as in case I. This is also valid for the extreme values, i.e. maxima and minima of investment in each market. One interesting fact is worthwhile noting. In the last market phase, the difference between the maximum and the average is bigger than the difference between the minimum and the average. This effect is the strongest in cases II and III, where the search intensity of the active customers, λ_1, is relatively high. The asymmetry decreases as λ_1 decreases (case IV), and the phenomenon vanishes as both search intensities λ_0 and λ_1 decrease (case I). A large asymmetry means that there are few firms investing much money and many firms investing little money. Since — as already shown above — a high λ_1 favors exactly this structure it is not surprising that, for instance, in case I, where there are mostly patronizing customers, investment as well as profits and firm size are almost equally distributed.

If investment is regarded irrespective of the firm size, the pattern of Figure 4.3 is obtained. As already mentioned above, it is worthwhile making a distinction between total investment and investment per unit of capital. The solid line shows the capital stock of the firms, sorted in ascending order. The crowd of points marks the values of investment per unit of capital (multiplied by 200 for better comparison) for all firms that are in the market at a given point of time ($t = 20$; 60; 100).[10] Each point of the crowd corresponds to one firm on the solid line. As the number of firms plotted is quite large, a crowd emerges. The values on the horizontal axis indicate the number of active firms.

At the first glance, the general pattern is similar for all cases. Small firms invest more money per unit of capital than large firms. The shape of the dots also shows a higher variability of investment per unit of capital for small firms, and it shows a relatively clear border of the maximum and minimum amounts spent by the firms. As pointed out earlier, the differences in capital stocks in the first phase of case I are less than in the other cases in phase I. This can be seen at the slope of the solid line. As the market develops, after phase II ($t = 60$) more firms are in the market. The maxima reached by small firms have increased whereas those of large firms have decreased slightly. Comparing firms of the same size, it can be noted, that those firms that have been the largest firms in $t = 20$ are in $t = 60$ only medium-sized and spend more on investment than in the previous phase. Only those firms which have grown large in phase II spend in $t = 60$ a smaller amount of money than the formerly large firms in $t = 20$. In phase III of case I a reduction in firm size can be observed. There is an increase in the upper bound of investment of small firms, but the dots are more concentrated in the lower area. Medium-sized and large firms invest less than in the phases before.

In case II ($\lambda_0 = 0.6$; $\lambda_1 = 0.4$), and case III ($\lambda_0 = 0.8$; $\lambda_1 = 0.6$) firms are in all three phases more heterogeneous than in case I. In phase I of cases II and III, investment per unit of capital is less dispersed for higher search intensities. The borders of the

[10]Multiplying both gives the total investment shown in Figure 4.2.

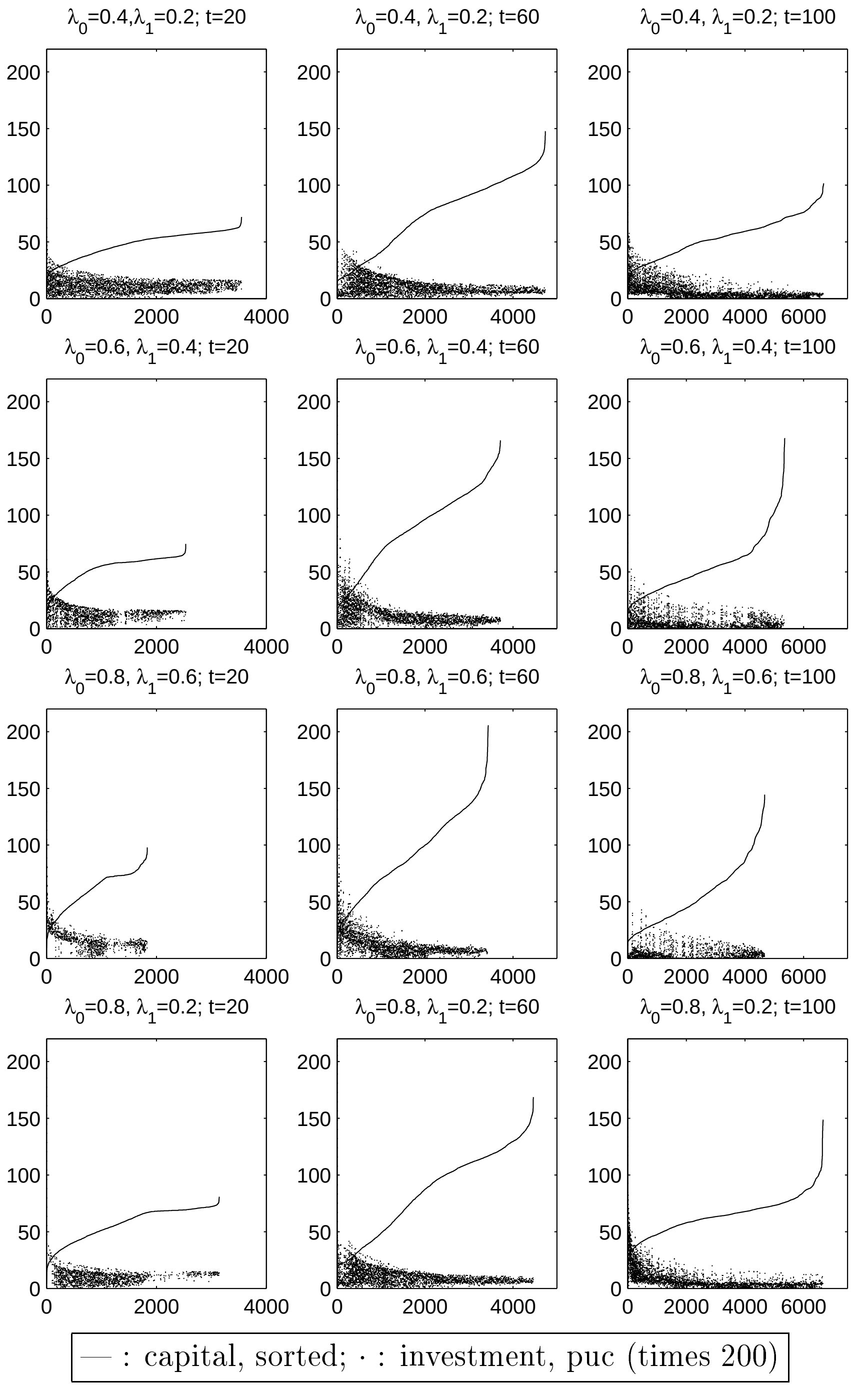


Figure 4.3: Investment per Unit of Capital

crowded points are less clear than in case I, and in the cases II and III where the search intensities are higher, the number of firms in the market are less. In phase II of the cases II and III, investment of small firms is higher than in phase I, and there are more large firms. In phase III, where the average capital stock has declined, investment per unit of capital is on average smaller than in the previous phases. A large proportion of firms has reduced investment to a minimum level as in case I. The major difference between cases II and III and case I is that with increased search intensities in phase III of cases II and III the variability of investment per unit of capital seems to be larger, but there are less firms investing more than the minimum amount than in case I.

Case IV illuminates the effects originating from λ_0 and λ_1. The varying extent of the investment is caused by λ_1. In all three phases of cases I and IV the crowd of points is similar in its extent whereas in cases II and III there is a different pattern. λ_0 is responsible for the distribution within the borders determined by λ_1. For increasing λ_0 investment per unit of capital appears to be more concentrated. This means, that for investment per unit of capital a high search intensity of potential consumers has the effect that firms behave more similar because of the random distribution of new customers to firms.

Profits and Performance

To some extent, profits reflect the capability of firms to adjust to the environmental conditions. Studying their development it is remarkable that the development of profits and performance is not as smooth as the development of the capital stock. Particularly in the first market phase one can observe an adjustment process that is the more distinct the higher the search intensity of potential consumers is.

The development of the average profits and the resulting measure of firm success, performance (solid line), their minima and maxima (dashed lines) and their standard deviation (dotted lines) are shown in Figures 4.4 and 4.5, respectively. Two waves occur in all four cases for the average profits as well as for the average performance. The first wave occurs just in the beginning (in the first 10 periods). It is more distinct for higher λ_0, i. e. it is mostly caused by the search activity of potential consumers. The strength of the wave depends positively on the level of λ_0. The

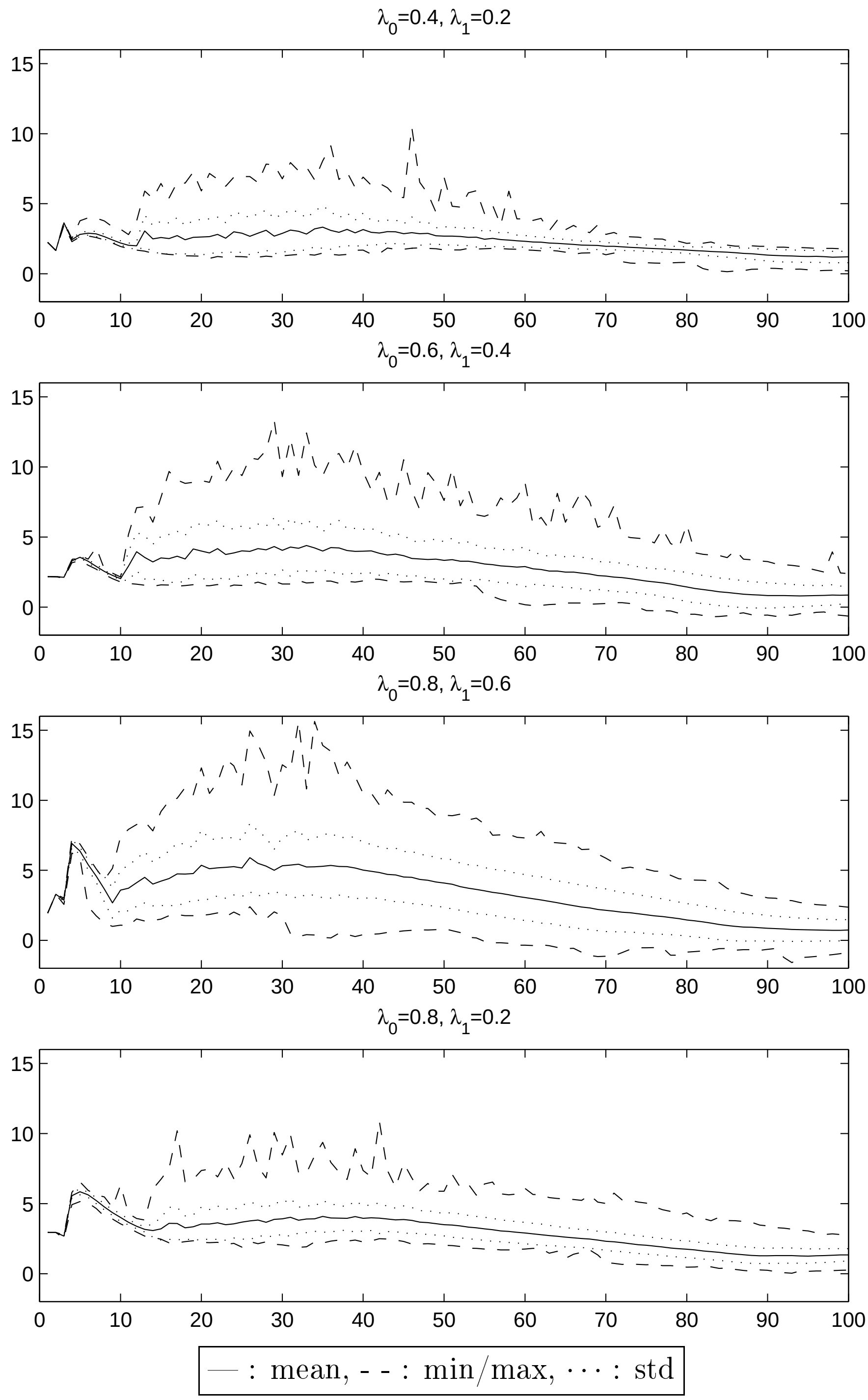


Figure 4.4: Average Profits

small difference between case III and case IV results from the difference in λ_1 in both cases.

The second wave is a long one occurring after the random effects of the large flows out of the potential consumers are relaxed. In the cases I, II, and III the second wave is the more distinct and has a higher level, the higher the search intensities are. Since in case IV the second wave is as flat as in case I, λ_1 seems to have the major influence on this wave. The search intensity of the actual customers also affects the level of the average profits at the end of the run ($t = 100$). Case IV (1.3377) has the highest level, followed by case I (1.2008) $>$ case II (0.8639) $>$ case III (0.7416).

The average profits in cases I, II, and III depend mainly on λ_0 and are ranked as case I (2.3027) $<$ case II (2.7256) $<$ case III (3.3306). The higher average profits in case IV (2.9705) compared to those of case I (with the same λ_1) result from the random effect due to the fact that firms in case IV benefit from potential consumers.

The standard deviation of profits, i. e. the difference in profits between the firms in the same market, is positively related to the search activities of the actual customers, λ_1. Therefore, the lowest standard deviation is observed in cases I and IV, whereas in cases II and III, the differences between firms are bigger. This is because for low λ_1 most of the customers remain loyal to their suppliers so that the customer base of a firm remains relatively constant from the beginning.

In general, two phases can be distinguished in the development of profits. During the first periods, there is a strong random effect of λ_0, which vanishes after about 10 periods. Then, the influence of the actual customers becomes stronger although the level of the average profits depends mainly on λ_0. A more detailed analysis of the profitability of the firms is performed together with the analysis of concentration on page 157.

The performance of a firm is per definition highly correlated with the profits.[11] Therefore, Figure 4.5 that shows the development of the average performance is similar to Figure 4.4 which presents the profits. On average, performance is larger for high λ_0 so that the smallest value is observed for case I, where case I (2.3460) $<$ case II (2.7998) $<$ case III (3.3902). The average performance in case IV (3.0016) is slightly smaller than that of case III. Because of the strong relation between profits

[11] See Equation (3.1), p. 71 in Chapter 3.

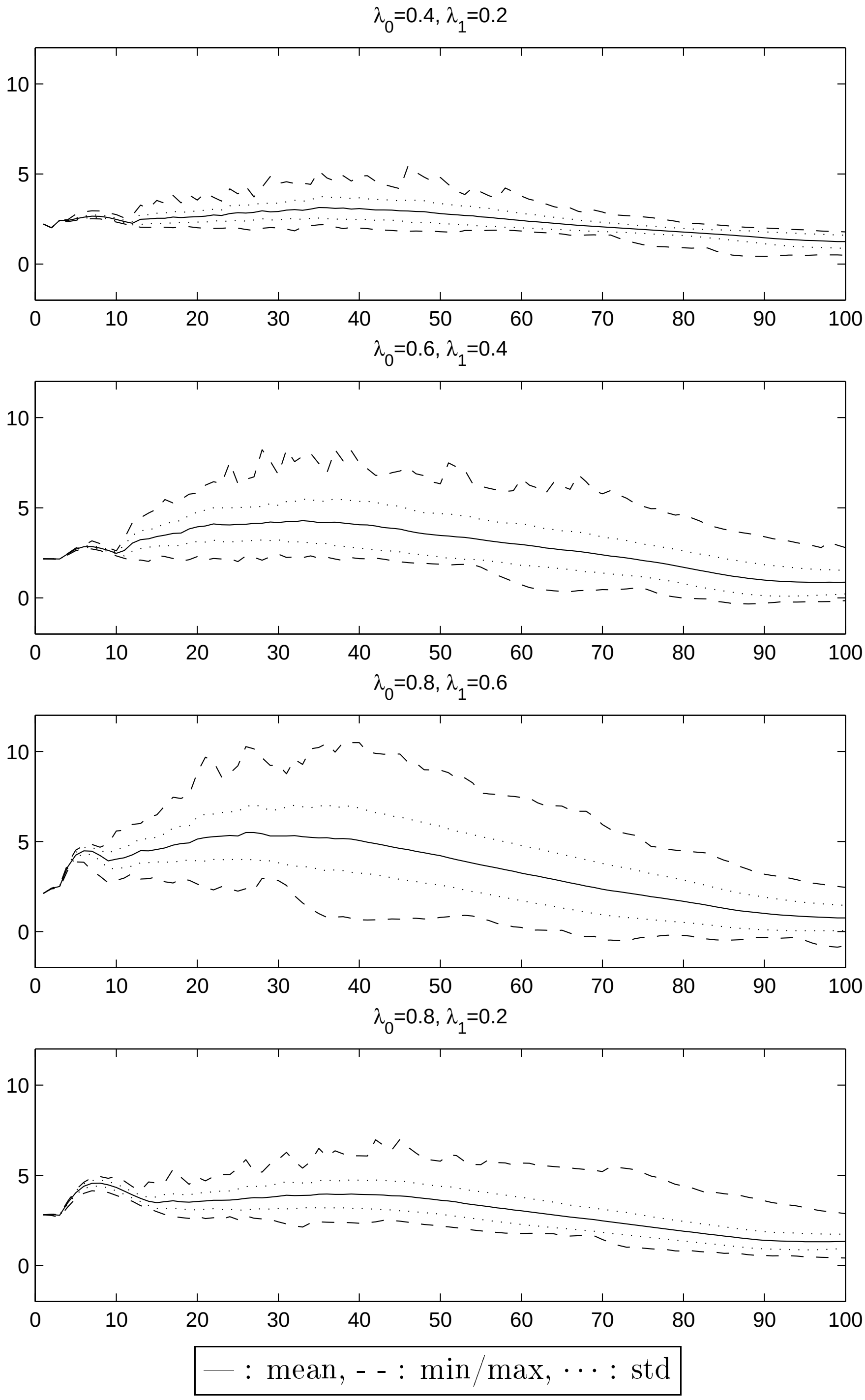


Figure 4.5: Average Performance

and performance, in the last periods the values for the corresponding markets are approximately the same. Thus, the average performance among the markets in the last period is: 1.2479 (case I) $>$ 0.8728 (case II) $>$ 0.7618 (case III). The largest average performance is observed in case IV (1.3371). That is, low search activities of actual customers yield a high average level of performance at the end of the run.

The standard deviation is more strongly positively related to λ_1 than to λ_0. Differences in firms' performance are bigger for higher λ_1, as argued above in the case of profits. The minima and maxima of the average performance have to be less extreme than those of the average profits by definition. This also explains the similarity of the values at the end of the run in period $t = 100$.

The question if these differences in profits and performance are persistent or if they converge to a certain value is also discussed in the literature. DOSI et al. (1997) and SCHMALENSEE (1989) support persistent differences in profits as well as in other firm characteristics. The analysis of the market structure below also gives evidence for the persistence of differences in profits.[12]

Research and Development

How the process of R&D depends on the search activities of the two types of consumers is one of the most interesting features of the simulation results. The first point to note is that active customers have a major influence on the level as well as on the variance of R&D expenditures. The expenditures are high if active customers search with high intensity. That is, firms are compelled to supply their goods at low prices, which can only be done if production costs are low, for instance, by engaging in R&D. Comparing the outcome of the R&D process for different search intensities with respect to the number of imitations and innovations and the cost reduction leads to a remarkable result. Although firms spend more on R&D, the average cost reduction is smaller and fewer new technologies have been developed.

The average R&D expenditures, differentiated into imitative and innovative efforts, are presented as solid lines in Figure 4.6. In the left column, the different cases are shown for imitation, and in the right column they are shown for innovation. The corresponding minima and maxima and standard deviations are represented by the

[12]See Figure 4.22, p. 155.

dashed and dotted lines, respectively. Common to all cases is an increase in R&D expenditures during the first two market phases, followed by a decrease in the last phase. The initial values for all firms are 0.002 for expenditures on imitative efforts and 0.005 for innovative efforts per unit of capital. The values which are plotted are the total expenditures, i. e. expenditures per unit of capital multiplied by the capital stock.

Concerning the expenditures on imitation (left column), one can see that in cases II and III, where the search intensities are higher, the increase and the decrease of the expenditures on imitation are larger than in case I. Surprisingly, the peak in case III is lower than in case II. On average, imitative efforts are the smallest in case I (0.2179), followed by case II (0.2410) and case III (0.2454) which are very similar. At the end ($t = 100$), the average expenditures are the smallest in case III (0.2591) $<$ case II (0.2751) $<$ case I (0.2819). Furthermore, the standard deviation is higher in cases II and III compared to case I, where there is hardly any difference between the standard deviation of cases II and III. The extreme values show a different pattern. Whereas in case II the upper extreme values are larger than in case III, for the lower extreme values the opposite is true, i. e. in case III the minimum amounts spent on imitative efforts are lower than in case II.

Analysing case IV shows that λ_1 causes the level of the standard deviation, i. e. the higher λ_1, the larger is the standard deviation and the larger are the extreme values, minimum and maximum. In case IV, the firms spend 0.2372 in imitative efforts on average, which lies slightly below the expenditures of case II. At the end, the expenditures on imitation are 0.3179, which is the highest amount of all four cases. That is, λ_1 influences the average expenditures positively, but also generates low values at the end. The peak is influenced by λ_0. For high λ_0 the increase is stronger, i. e. in case III the peak is higher than in case I, and in case IV the peak is similar to that in case III.

The average expenditures on innovative efforts show a similar pattern. First, an increase in λ_0 increases the peak of the average expenditures, where cases II and III are quite similar. The effect that λ_0 has on the peak seems only to be present for low λ_0. For values above $\lambda_0 = 0.6$, a further increase has no effect on the peak. The decrease after the peak was reached is clearly higher in cases with high λ_0. The average expenditures are the lowest for low search intensities, i. e. case I (0.3955) $<$

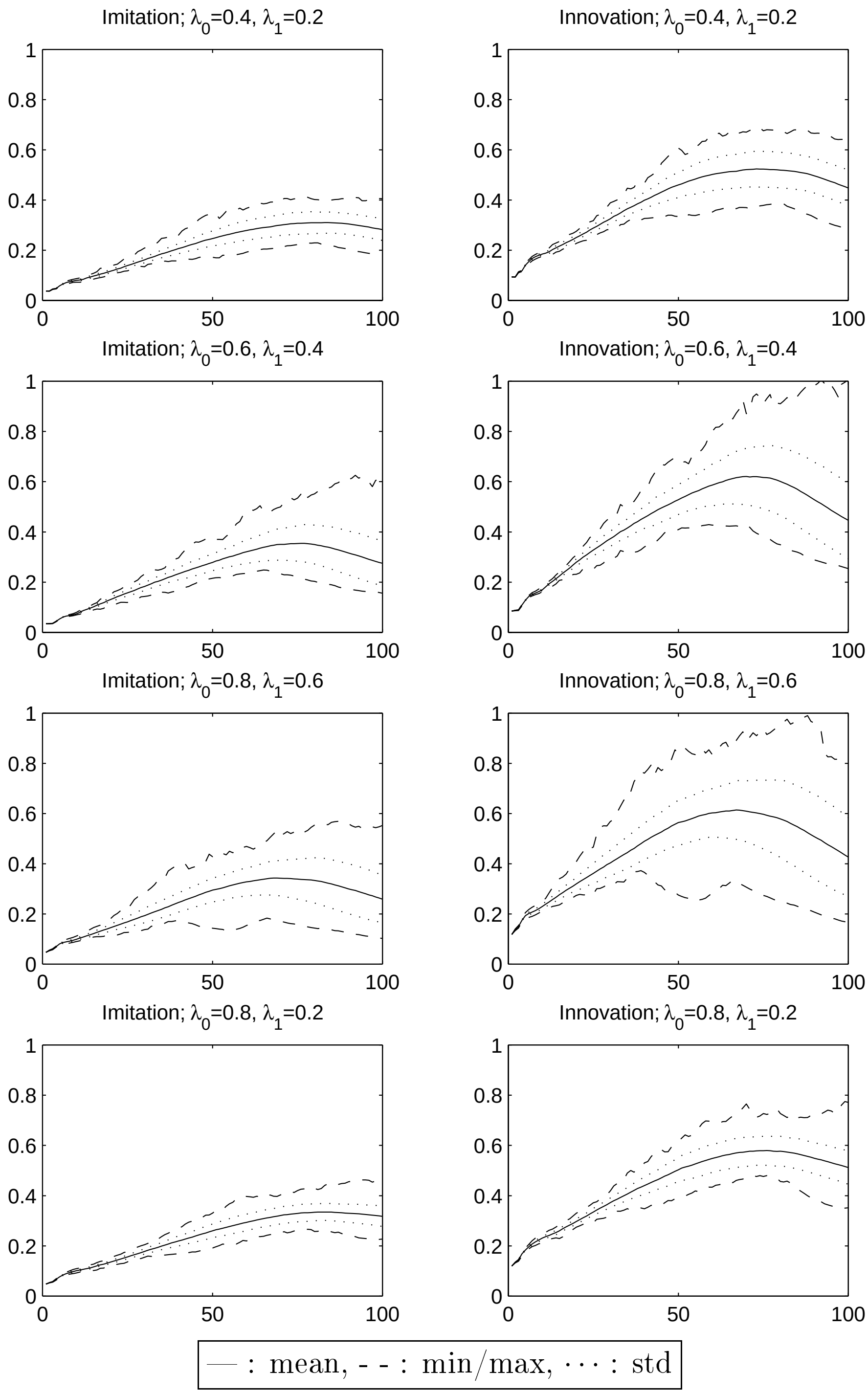


Figure 4.6: Average R&D Expenditures

case II (0.4440) $<$ case III (0.4610). The average of case IV is 0.4436 and, therefore, less than case II but larger than case I. At the end, firms spend most money in case IV (0.5119) $>$ case I (0.4477) $>$ case II (0.4461) $>$ case III (0.4266). Therefore, λ_1 has the mixed effect that it is positively related to the average, and negatively related to the expenditures at the end. The standard deviation is increased by a high λ_1, and the extreme values increase, where the deviation of the maximum from the average becomes larger than the deviation of the minimum from the average.

Comparing imitative and innovative efforts one can see that the increase during the run relative to the initial values is larger in all four cases for imitation than for innovation although the absolute level spent on innovations is still higher. One reason might be that the initial values for innovative expenditures per unit of capital are larger than for imitative expenditures. Another reason might be that innovations lead to more effective results than imitations, measured by the decrease in production costs.

High expenditures on R&D do not guarantee an improvement of the technology. They only increase the probability with which an imitation or an innovation may be carried out. The "success" of the imitation and innovation process resulting from the R&D expenditures is documented in Figure 4.7 and Table 4.4.

Figure 4.7 shows the number of imitations (solid line) and the number of innovations (dashed line) for the four cases. For simplicity, the number of innovations is multiplied by 20 in the figure. The number of imitations is much larger than the number of innovations. This originates from the random process that generates imitations with a higher probability. Both, the number of imitations as well as the number of innovations increase during the first two market phases. In phase III, they slow down. This corresponds to the pattern of the average R&D expenditures. In Figure 4.6 it is shown that after a steady increase in the first two market phases, the expenditures decrease in the last market phase. Interestingly though, the patterns of the R&D expenditures and the number of imitations and innovations are not identical.

Concerning first the imitations, there are 27.2998 imitations in case I $>$ 22.7256 (case II) $>$ 19.4511 (case III), and 27.3039 in case IV on average. The number of imitations increases in the first phase and amounts in period $t = 20$ to 11.96 (case I) $>$ 9.82 (case II) $>$ 7.40 (case III), and 12.37 (case IV). In period $t = 60$ the number of imitations increases further to 32.70 (case I) $>$ 28.11 (case II) $>$ 24.98 (case III),

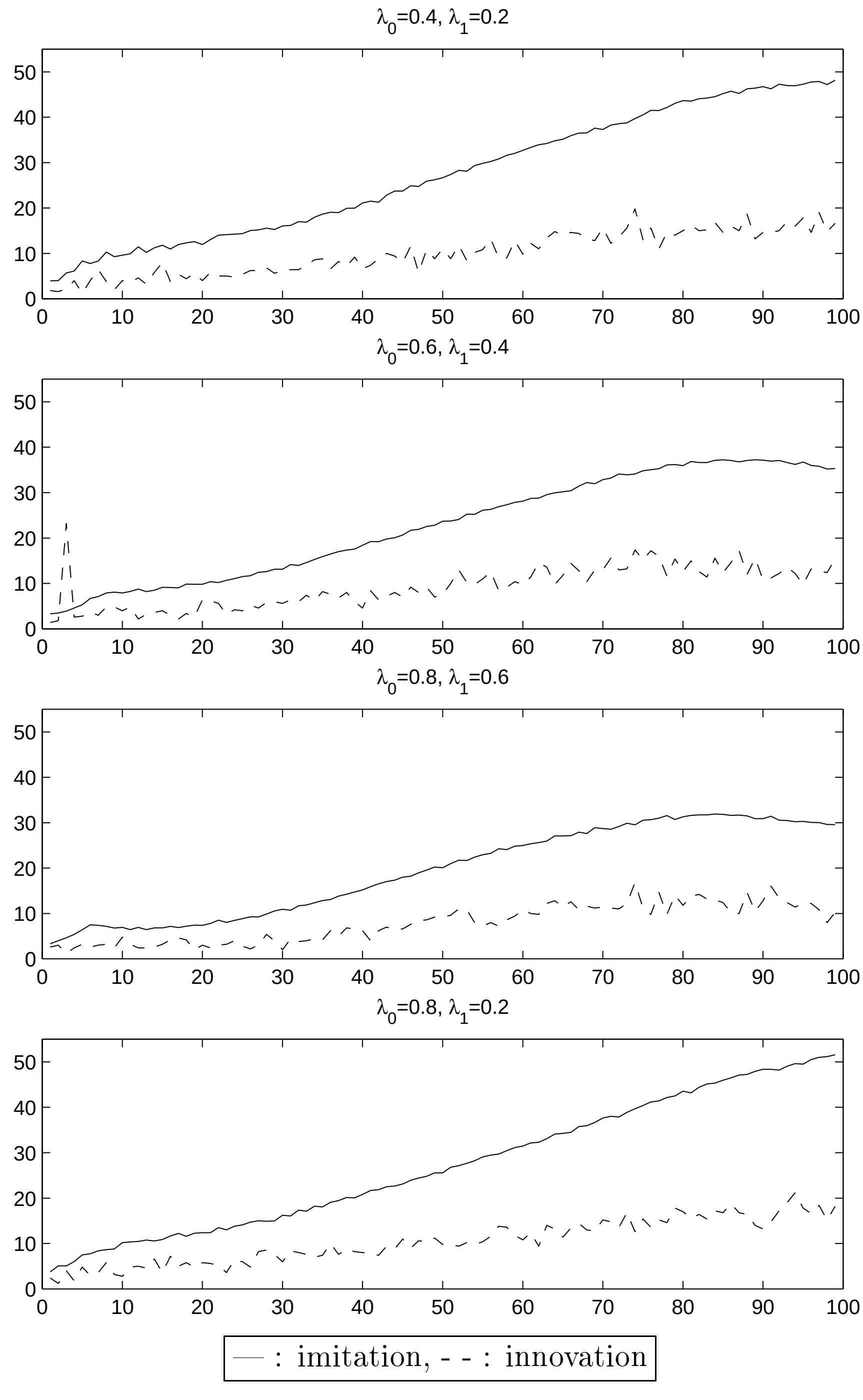


Figure 4.7: Average Number of Imitations and Innovations

and 31.46 (case IV). At the end, the values are 48.13 (case I) $>$ 35.31 (case II) $>$ 29.56 (case III), and 51.59 (case IV). The trend shows that the number of imitations depends negatively on λ_1. In cases I and IV, the number of imitations is the highest for all three phases. The number of imitations in case II is larger than in case III for all phases. For the cases II and III a slight decline in phase III can be observed. In cases I and IV, where λ_1 is low, the number of imitations increases steadily in all phases. Concerning imitations, the search activity of the potential consumers, λ_0 seems to have little effect.

The number of innovations is smaller than the number of imitations because the probability of an innovation is lower per definition. On average, there are 0.4991 innovations (case I) $>$ 0.4593 (case II) $>$ 0.3914 (case III), and 0.5227 (case IV). Innovations also appear to depend negatively on the search activity of the actual customers, λ_1. In contrast to the number of imitations, the number of innovations does not increase so steadily. For example, neither in period $t = 20$, the number of innovations follows the order of λ_1, with 0.20 (case I), 0.32 (case II), 0.15 (case III), and 0.29 (case IV), nor in period $t = 60$ with 0.49 (case I), 0.49 (case II), 0.54 (case III), and 0.54 (case IV). Therefore, only the average number of innovations depends negatively on the search activity of the actual customers, λ_1. The search activity of the potential consumers, λ_0, has little effect as is the case of imitations.

Divided into the three phases, the average number of imitations and innovations are presented in Table 4.4. For each phase, the left column contains the average number of imitations and the right column contains the average number of innovations in the corresponding phase.

Table 4.4: Number of Imitations and Innovations

Phase[a]	Phase I		Phase II		Phase III	
Case	im	in	im	in	im	in
Case I	11.6524	0.2373	26.8170	0.5009	43.4300	0.7591
Case II	9.3479	0.2388	23.2861	0.4627	35.5427	0.6764
Case III	7.7197	0.1582	20.2209	0.4121	30.4127	0.6039
Case IV	11.4445	0.2603	26.1694	0.5112	44.2979	0.7967

[a]Phases I, II, and III cover the periods $t = 1$ to 33, $t = 34$ to 66, and $t = 67$ to 99.

Table 4.4 confirms the findings of Figure 4.7 with respect to the number of imitations. It is higher for low search activities of the actual customers. Furthermore, the average number of imitations increases from phase to phase. Concerning innovations, for the average number of innovations in the phases, the values in the table show that in each case there is an increase. In case IV, where both groups of consumers search with a high intensity, the number of innovation is in all phases larger than in the other cases. In the first phase, the numbers of innovations in cases I and II are similar. In all other phases, the differences are bigger and follow the usual pattern, i. e. the average number of innovation decreases as the search activity of the actual customers, λ_1, increases.

Concerning the above-mentioned variables, such as capital stock and profits, there have always been different effects of the search activities of the two groups of consumers on their means and levels of the standard deviation. Here, the results indicate little effect of the activities of potential consumers, but a clear effect of the activities of actual customers. This leads to the conclusion, that most of the firm characteristics depend on the number of customers that have been randomly matched and that buy goods from a certain firm because of the prices it charges. The situation changes if one considers the firm policy concerning R&D expenditures. Obviously, the firms follow a certain strategy in determining how much they intend to spend on insecure R&D activities. Their rationale is to invest more money in R&D if their environment is relatively unstable, i. e. if λ_1 is high. Obviously, firms do not take into account the randomly matched consumers because their number and behaviour is hard to predict. As a result, there is no base on which they can build their strategies. The only secure factor to be taken into consideration is the number of their actual customers, whom they try to keep by offering low prices. Besides, they have to ensure that their own prices are low compared to their competitors' prices. This is a very difficult task if their customers search with a high intensity and, therefore, increase competition. If their customers have high search costs, they stay relatively long at the same firm because they are badly informed about the prices of the other sellers. In that case, the firms have a secure customer base to operate from, and the pressure of patronizing customers who possibly change the supplier is relatively low. Thus, there is no need to reduce the price as much as if the actual customers search with a high intensity for better opportunities. However, the firms' strategy concerning R&D expenditures seems to be a passive strategy to secure or to slightly improve their market position. In general, R&D expenditures are not used as aggressive strategy to enhance competition actively.

It is noticeable that, on the one hand, the average R&D expenditures increase as λ_1 increases, but, on the other hand, the number of imitations and innovations decreases. Table 4.5 shows the average cost reduction per imitation and innovation draw. That is, all possibilities of improving the technology are counted, although not all attempts are fruitful.

Table 4.5: Average Cost Reduction per Draw

Case	Δcost per imitation	Δcost per innovation
Case I	0.0020	0.1112
Case II	0.0013	0.0666
Case III	0.0017	0.0850
Case IV	0.0017	0.0884

The average cost reduction in relation to the possibilities obtained is strictly higher for innovations. This means that on average a change in technology due to an innovation leads to a stronger decrease in production cost than a change in technology caused by an imitation. In case II, imitations as well as innovations are least effective. A clear system concerning the search intensities cannot be observed.

Table 4.6 illuminates the "profitability" of R&D expenditures. The average cost reduction in relation to one unit of money spent on R&D divided into imitative and innovative efforts is shown. From one unit spent on in imitative efforts the average cost reduction is larger than in the case of innovation. That is, it is more expensive to invest in innovation than in imitation. For imitations as well as for innovations an environment where the search activity of the actual customers is relatively low seems to have a positive impact on the average cost reduction per unit of R&D expenditures.

To extend the analysis of R&D expenditures, their major determinants are studied. Expenditures on R&D seem to depend more strongly on profits than on firm size. Schmalensee (1989) states that profits are positively related to R&D (at

Table 4.6: Cost Reduction and R&D Expenditures[a]

Case	Δcost (imitation)	Δcost (innovation)
Case I	0.8270	0.7871
Case II	0.7366	0.6584
Case III	0.7251	0.6675
Case IV	0.8386	0.7936

[a]The cost reductions are measured per unit of imitative (left column) and innovative (right column) R&D expenditures.

least unless concentration is high) and, in surveying the literature, SYMEONIDIS (1996) concludes that most of the empirical studies hardly find any evidence for the Schumpeter-II hypothesis that innovations are positively related to firm size (if it is true then only up to a certain degree). This is also in line with the inverse U-shaped relation between innovation and concentration found by FLAIG and STADLER (1994).

Figure 4.8 shows the total expenditures on R&D firms spend on average (the crowd of points). The expenditures are sorted by capital and multiplied by 100 for simplicity. The solid line shows the capital stocks of firms, ranked from the smallest to the largest from the left to the right. Each point of the crowd corresponds to a firm of a given size. The figure shows that large firms spend more on R&D on average than small firms. If the total R&D expenditures are analysed for different phases of the market development, it can be seen in Figure 4.8 that during the first phase, R&D expenditures of large firms are disproportionately low compared to their capital stock. In phase II, R&D expenditures are nearly proportional to capital, whereas in the last phase, the total expenditures on R&D are higher per unit of capital than in the previous phases.

In Table 4.7, the mean and standard deviation of the total expenditures on R&D are reported.[13] For each case an increase of the average expenditures can be observed from phase I to phase II, and a decrease from phase II to phase III. The order of the R&D expenditures in the four cases is different for each market phase. In the

[13]This has already been visualized in Figure 4.6.

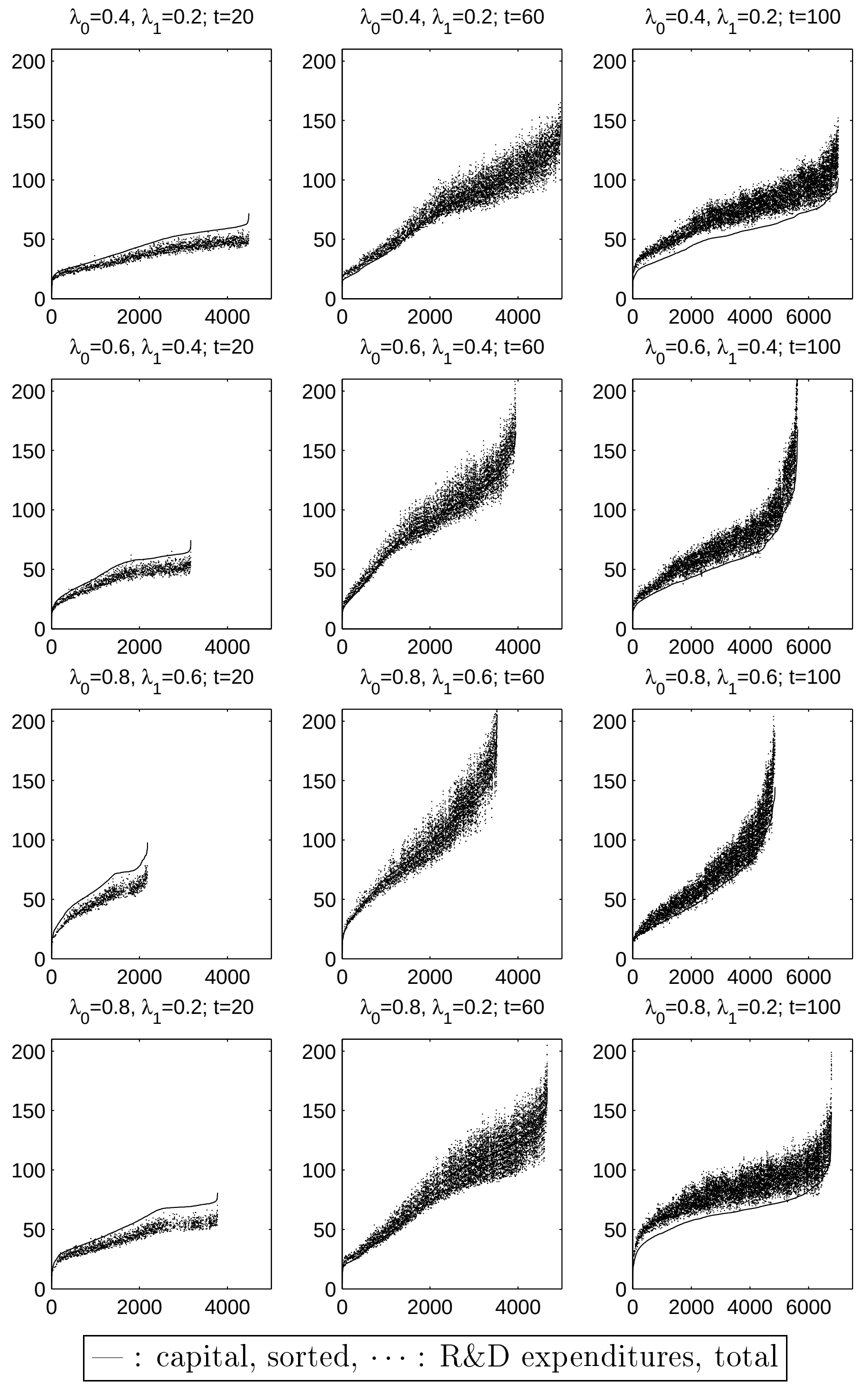


Figure 4.8: R&D and Firm Size

Table 4.7: Total R&D Expenditures

Phase[a] / Case	Phase I		Phase II		Phase III	
	mean	std	mean	std	mean	std
Case I	0.3660	0.0981	0.7675	0.3315	0.7182	0.2379
Case II	0.4086	0.1063	0.8865	0.3756	0.6981	0.3288
Case III	0.4642	0.1364	0.9146	0.4165	0.6781	0.3529
Case IV	0.4318	0.1140	0.8352	0.3790	0.8194	0.2219

[a]Phases I, II, and III are represented by the periods $t = 20$, $t = 60$, and $t = 100$.

first phase, average expenditures increase due to an increase in λ_0, whereas in phase II, λ_1 seems to be the major determinant of the level of expenditures. In phase III, things have turned around. From case I to case III, the average expenditures decrease as λ_1 increases.

The relationship between the R&D expenditures and the capital stock, and the relationship between R&D expenditures and profits are shown in Tables 4.8 and 4.9. The results are reported for total expenditures (first column of each phase) as well as for the expenditures per unit of capital (second column of each phase).

The correlation between total R&D expenditures and capital is highly positive per definition. If the correlation between R&D expenditures per unit of capital and capital is regarded, the relationship is negative. The negative correlation in each

Table 4.8: Correlation between R&D and Firm Size[a]

Phase[b] / Case	Phase I		Phase II		Phase III	
	total	puc	total	puc	total	puc
Case I	0.9633	-0.4297	0.9590	-0.3561	0.9310	-0.0713
Case II	0.9583	-0.2710	0.9632	-0.1521	0.9607	0.0438
Case III	0.9704	-0.1173	0.9605	0.2439	0.9576	0.0584
Case IV	0.9624	-0.4297	0.9436	-0.2853	0.8981	-0.0782

[a]The first column in each phase shows the correlation between firm size and the total R&D expenditures (total), and the second shows the correlation between firm size and R&D expenditures per unit of capital (puc).
[b]Phases I, II, and III are represented by the periods $t = 20$, $t = 60$, and $t = 100$.

phase is the highest for a low value of λ_1 (cases I and IV). The correlation decreases as λ_1 increases. In case III of phase II, the correlation becomes positive, but the ranking remains. It is only in the cases I and IV that the correlations remain negative in phase III; for cases II and III there is a positive correlation. Taking into account the extent of the correlation, one can see that in phases I and II the correlations are relatively clear, whereas in phase III the correlation between R&D expenditures per unit of capital and capital has nearly vanished. In tendency, large firms spend less money on R&D per unit of capital than small firms.

Regarding total R&D expenditures, there is a highly positive correlation for each case in all phases. Consequently, large firms spend more money on R&D than small firms. This is simply because R&D expenditures per unit of capital are very small compared to the capital stock. A clear pattern concerning the influence of search activities on the correlation between total R&D expenditures and firm size cannot be found.

The relationship between R&D and profits is visualized in Figure 4.9. The solid line shows the profits of the firms in ascending order. For the firms, the corresponding R&D expenditures are plotted, which form a crowd of points. In phase I, the differences of profits among firms are very big and decrease from phase I to phase III. R&D expenditures per unit of capital and profits are negatively correlated. This is because large firms invest more money in R&D in absolute volume, but per unit of capital a small firm has higher R&D expenditures. In phase II (and in tendency also in phase III), firms with the same profits have more variability in their R&D expenditures. This can be seen in the range of R&D expenditures in phase II which is thicker than in phase I. The same is valid for phase III.

The correlation coefficients between R&D expenditures and profits are summarized in Table 4.9. For each phase, the first column shows the correlation between total R&D expenditures and profits, and the second column shows the correlation between R&D expenditures per unit of capital and profits. In phase I, there is hardly any relationship between R&D per unit of capital and profits in cases I and IV, where λ_1 is low. The positive correlation increases for cases II and III as λ_1 increases. In phases II and III the correlation for all cases is negative. In phase II, the correlation is higher for low values of λ_1, where a high λ_0 seems to increase the correlation slightly. For higher λ_0 and λ_1, the correlation decreases (cases II and III). In phase III, the

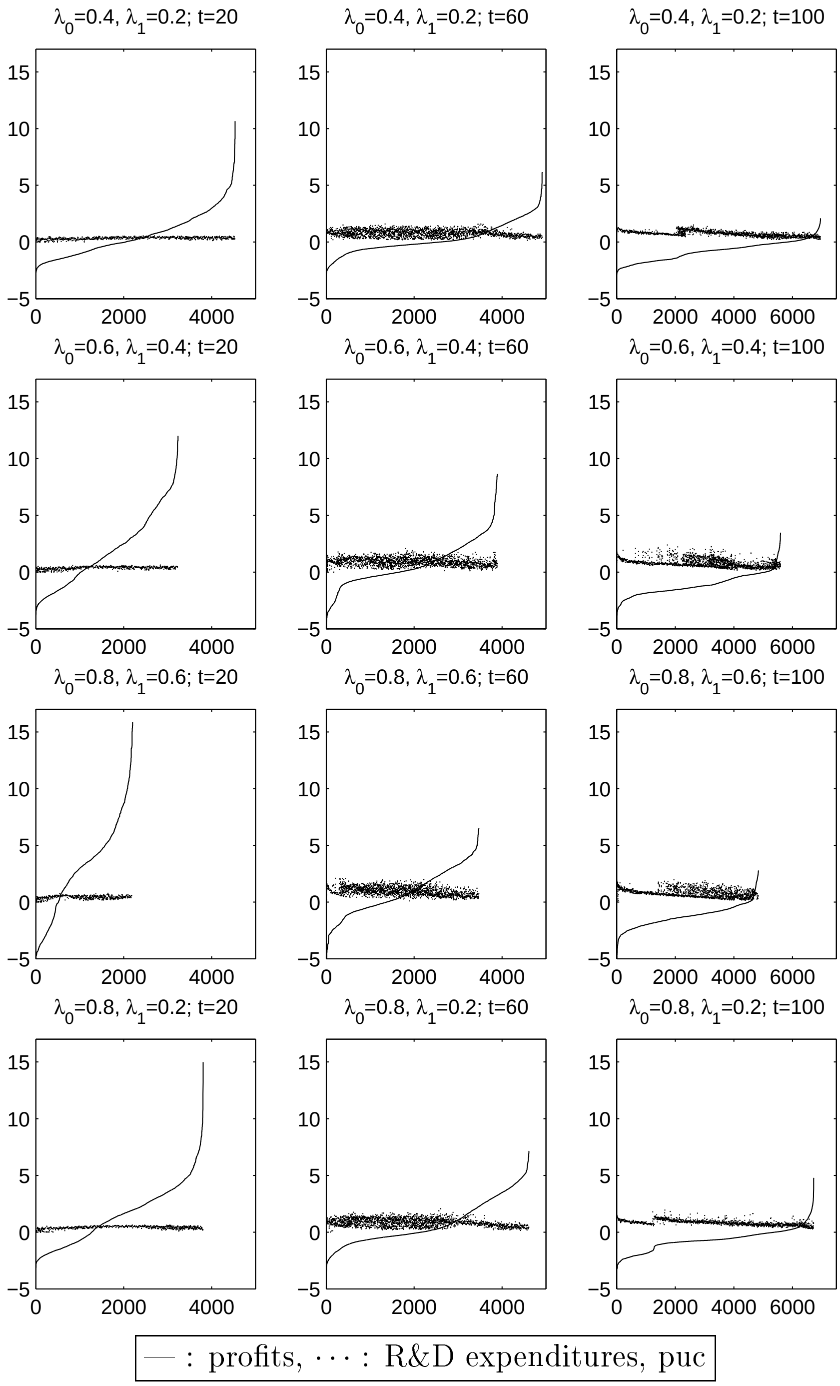


Figure 4.9: R&D and Profits

Table 4.9: Correlation between R&D and Profits[a]

Phase[b] / Case	Phase I		Phase II		Phase III	
	total	puc	total	puc	total	puc
Case I	0.3438	0.0448	-0.3161	-0.4197	-0.6002	-0.2054
Case II	0.3349	0.1426	-0.2734	-0.2445	-0.4866	-0.2281
Case III	0.1376	0.2107	-0.4050	-0.2479	-0.5042	-0.2235
Case IV	0.1405	-0.0196	-0.4364	-0.5024	-0.5918	-0.1758

[a]The first column in each phase shows the correlation between profits and the total R&D expenditures (total), and the second shows the correlation between profits and R&D expenditures per unit of capital (puc).
[b]Phases I, II, and III are represented by the periods $t = 20$, $t = 60$, and $t = 100$.

effects caused by the search intensities λ_0 and λ_1 vanish. The correlation remains negative around 20 per cent for all four cases. This is illustrated in Figure 4.9.

The correlation coefficients between total R&D expenditures and profits show a different pattern. Whereas in the case of R&D expenditures per unit of capital an effect of λ_1 has been detected at least in phases I and II, in the case of total expenditures, λ_0 seems to play a key role. In phase I the correlation for high λ_0 (cases III and IV) is much lower than in cases I and II with a relatively low λ_0. All correlation coefficients of phase I are positive. In phases II and III the correlation becomes negative. In contrast to phase I, a high λ_0 is associated with a higher correlation in phase II. A low λ_1 seems to increase the correlation slightly. The evidence is completely different in phase III. For low λ_1 the correlations are the highest (cases I and IV) where there seems to be no influence of λ_0.

With respect to the adjustment process of R&D policies as outlined in Equations (3.7) and (3.8) on page 78, Chapter 3, the different results concerning the capital stock and the profits are not surprising. As the adjustment of the R&D expenditures depends on profits, they should be more influential than the capital stock. This is valid at least for phases II and III. The capital stock has an indirect impact because the R&D policy is measured per unit of capital. Thus, large firms spend less money per unit of capital than small firms, but, in absolute numbers, large firms usually spend more money. It is important to note that this analysis implies that a firm's policy is strongly oriented towards the behaviour of its patronizing customers. If the firms learnt how to behave, particularly in phase II, there is a negative correlation between R&D per unit of capital and profits, and the correlation becomes higher for low λ_1. This means that successful firms invest less money in R&D per unit of capital than less successful firms. When the customer base is more secure, i. e. if λ_1 is low, firms invest less money in R&D, but the improvement of technology per unit of money spent is better than if λ_1 is higher.

The R&D expenditures seem to be beneficial in the first market phase in order to secure the revenues. For a new firm in a market, it is essential that a new firm in a market create a customer base. Therefore, the correlation between R&D per unit of capital and profit is positive in the first phase and it increases in λ_1. The fact that the negative correlation between R&D per unit of capital and profits becomes higher with a decreasing search intensity of the actual customers is in agreement with the previously mentioned finding that firms use their R&D strategy passively. The incentive to innovate or imitate is higher but less effective for high λ_1.

Production Costs

The development of the production costs for different λ_0 and λ_1 is presented in Figure 4.10. The solid line shows the average production costs, the dashed lines indicate the range of production techniques, and the dotted lines correspond to the standard deviation. For all cases, the production costs decrease over the course of time. They converge to their lower bound after 80 – 90 periods. At the end of the run ($t = 100$), the reduction of costs induced by innovation and imitation has reached nearly the same levels in all four cases, namely 0.0052 (case I), 0.0052 (case II), 0.0054 (case III), and 0.0051 (case IV). At the end of the run ($t = 100$), only in case IV there seems to be hardly any difference in production costs between firms. In the cases I, II, and III, the difference at the end appears bigger for higher search intensities. The comparison with case IV indicates that the rate of convergence is higher for high λ_1.

The level as well as the cross-sectional production costs cannot be clearly explained by the constellation of λ_0 and λ_1. The search intensity of both the potential consumers and the actual customers seem to have little effect on the decrease of the average production costs although there are differences between the four cases. The most obvious difference is the movement of the minimum and maximum. A jump of

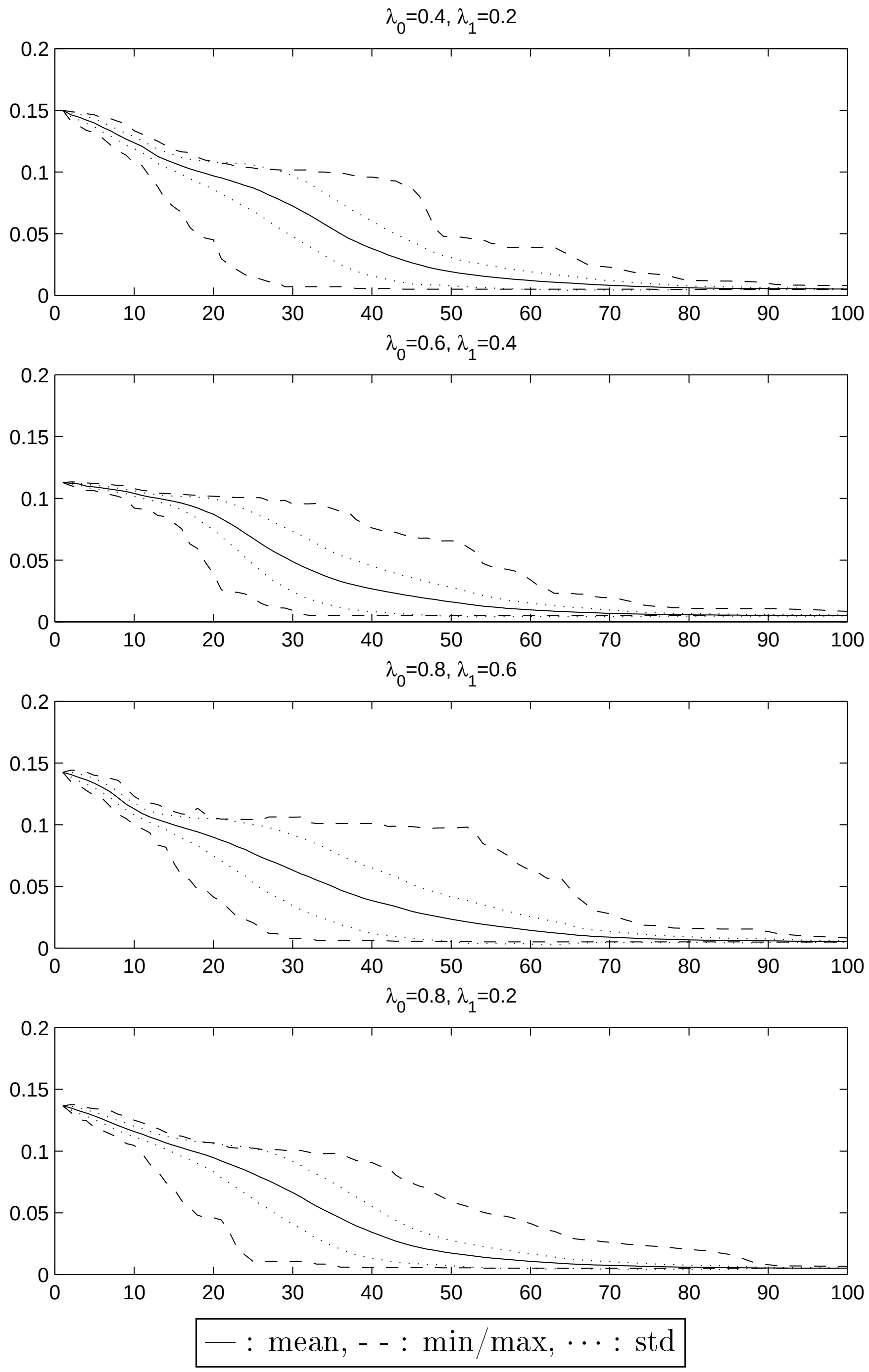


Figure 4.10: Average Production Costs

the minimum indicates the use of a new technology, whereas a jump of the maximum is probably caused by the exit of the firm with the largest production costs.

Consumers

An important factor of a firm's success is the number of customers a firm can attract because unsold stocks diminish profits and, therefore, limit the possibility of increasing the market share. It turns out that the initial mismatch of demand and supply decreases over the course of time. The most rapid and successful adjustment takes place if the active customers search with high intensity. This is reasonable because the pressure on the single firm to offer goods at a low price is higher. As will be shown later, as a consequence, the bankruptcy rate is also higher.

Figure 4.11 shows the number of customers and the amount of output sorted in ascending order. That is, the smallest firms are on the very left and the largest on the right. The line that is in bold type represents the amount of output supplied, and the dots (which look like spikes) indicate the demand a firm faces in the given period. Results are given for the periods $t = 20$, $t = 60$, and $t = 100$. The scales differ to ensure that the divergence between demand and supply remains complete.

In phase I, an excess demand can be observed for small firms, and an excess supply for large firms for all cases. This division is obvious. In phase II, the excess demand for small firms vanishes as λ_1 increases. For low λ_1 (cases I and IV) the excess demand for small firms remains. In the cases II and III, where λ_1 is relatively high, most of the large firms are able to adjust their output to the demand conditions. If λ_1 is low (cases I and IV), large firms as well as small firms have difficulty in adjusting their output. Note that there is also a greater number of firms in the market. This tendency becomes almost stronger in phase III.

Unlike cases II and III, cases I and IV imply that many firms (even small firms, and particularly medium-sized) cannot adjust their output to demand appropriately in phase III. Forecasting demand becomes more difficult for higher λ_1 because active consumers engage intensively in searching for a lower price. The divergence between demand and supply in all four cases increases from phase I to phase II. In the cases II and III of phase III, where λ_1 is relatively high, most of the firms are able to adjust their output to demand, but some of the largest firms have difficulties in doing so.

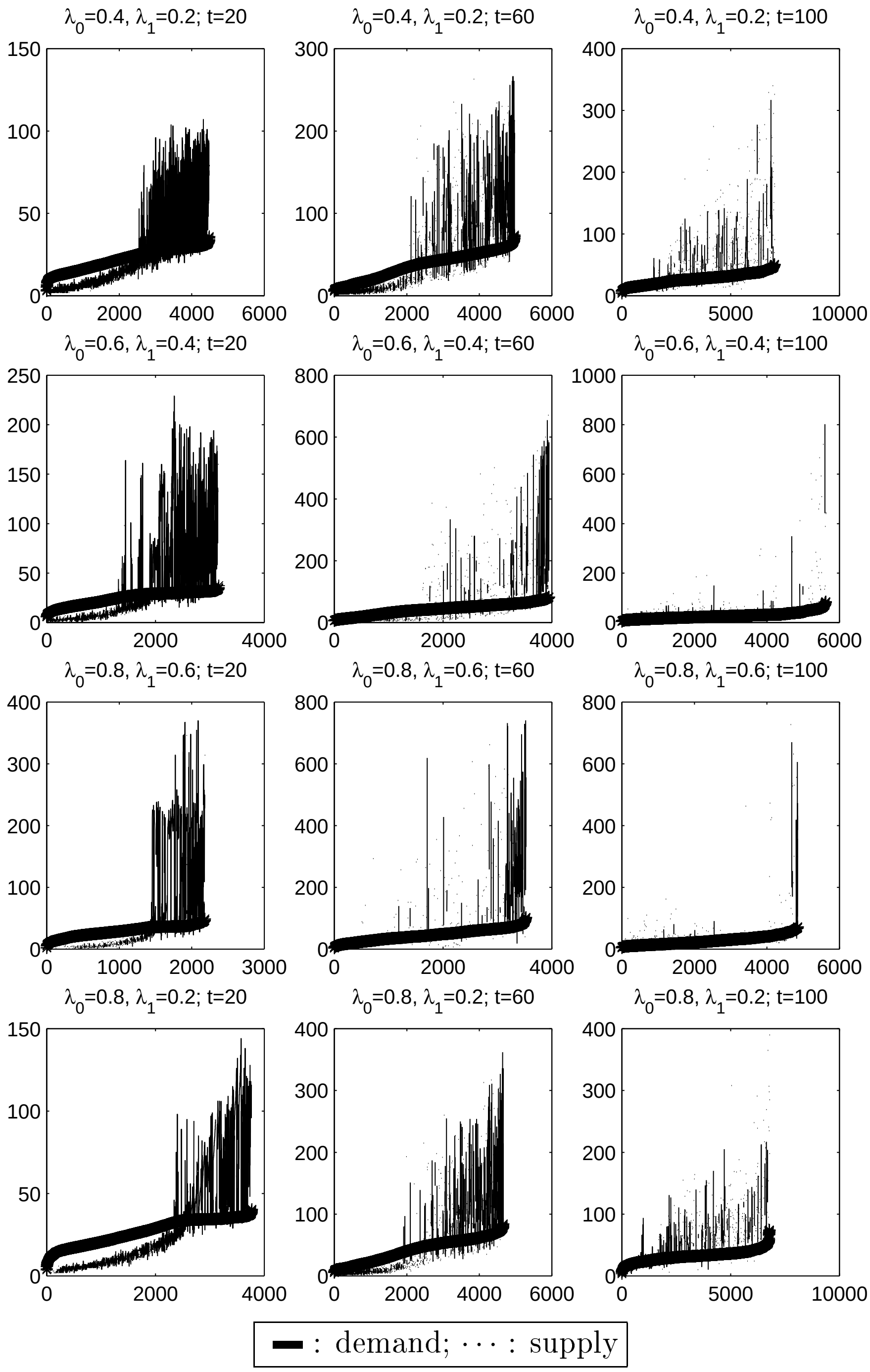


Figure 4.11: Demand and Supply

Gradually, firms learn how to adjust their output to their demand conditions. The incentive to learn is the stronger, the more price attentive their patronizing customers are. That is, in the first instance, it is more important for the firms to keep their customers than to attract new ones.

In addition to Figure 4.11, the average demand and supply in the market is shown in Figure 4.12. The major pattern discussed above is confirmed. The solid line, which shows the demand, first increases and lies above the average supply (the dashed line). After some periods, the relationship changes so that supply exceeds demand. Demand and supply roughly follow the typical life-cycle pattern of an industry. In the first phase, demand increases, before becoming satiated and decreasing afterwards. Supply reacts to demand with a certain time lag. Consequently, an excess demand is followed by an excess supply.

The point of time at which the relationship between demand and supply changes depends slightly on λ_1. If λ_1 is relatively high (cases II and III), the time span of excess demand lasts longer than if λ_1 is low (cases I and IV).

On average, supply exceeds demand in all four cases. Average demand amounts to 17.7361 (case I), 24.7366 (case II), 22.1757 (case III), and 20.2736 (case IV). Average supply is 29.1087 (case I), 34.0635 (case II), 35.0103 (case III), and 33.7644 (case IV). The effects of λ_0 and λ_1 cannot be easily distinguished because the random effect induced by λ_0 as well as the effect originating from λ_1 are contained in the demand of a supplier. One can, however, guess that the random effect is dominant in the early phases while the search activities of the actual customers are more influential in later phases.

This seems to confirm observations of new markets, where after a pioneering phase more and more firms enter the market because there is excess demand. The firms realize later that the demand has decreased (according to the life cycle of a product). Hence, most firms reduce their output and some of them exit the market (shake out). In this simulation, firms tend to shrink because they were not given the possibility of struggling.

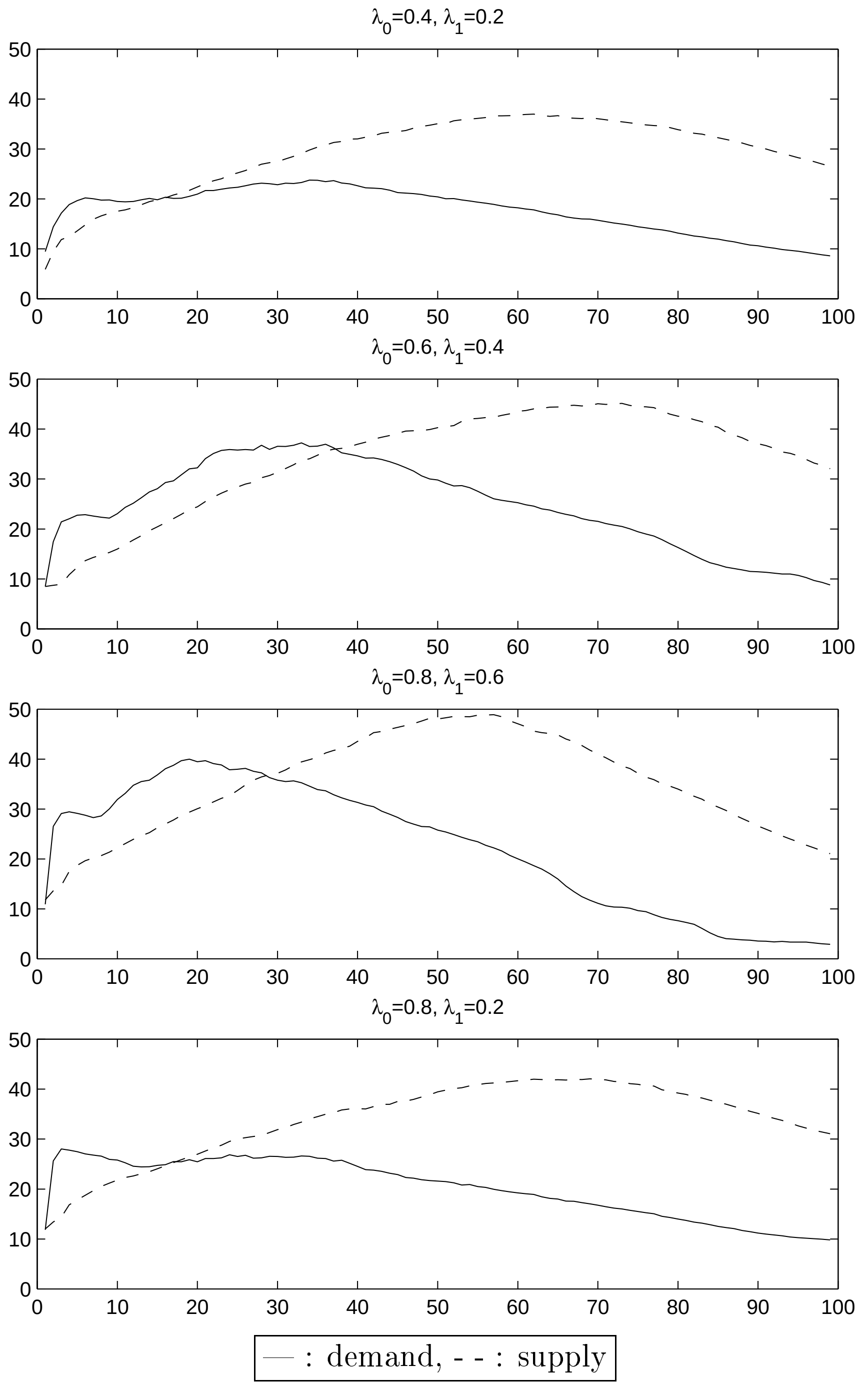


Figure 4.12: Average Demand and Supply

4.3.2 Price Distribution

The analysis of the price distribution is, together with the innovation process, one of the most interesting research objects of the simulation. It will be shown that the average price increases in the first market phase although production costs remain constant or decline. This is caused by the large number of potential consumers that makes firms charge high prices. When consumers become satiated the situation changes. The search activity of active customers dominates the influence on the price level so that firms charge lower prices when active customers search with high intensity. The price distributions that emerge are strongly skewed to the right and are shown to fit well to the lognormal distribution.

Figure 4.13 shows the capital-weighted[14] average prices (solid line), their standard deviation (dotted lines) and the minimum and maximum of each period (dashed lines) for the different cases of search intensities.[15] The development of the prices seems to be similar for all four cases. A price jump can be seen at the beginning of phase I. In the first third of the time the prices are relatively high and decrease slowly afterwards. Since in the beginning a random effect through a large flow of potential consumers dominates, firms use this effect and charge high prices. As many potential consumers have become active customers, the active customers in the market play a more decisive role. In contrast to the potential consumers, the search behaviour of actual customers is not random. It is oriented towards the prices of their sellers and their competitors' prices, which affects the price formation. Firms have an incentive to decrease product prices in order to keep their patronizing customers and to attract new consumers. The price competition becomes harder so that the decrease of prices will continue.

The higher the random effect generated by λ_0, the higher is the average price. This can be seen by comparing case I ($\lambda_0 = 0.4$, $\lambda_1 = 0.2$) with case IV ($\lambda_0 = 0.8$, $\lambda_1 = 0.2$). The average price for the whole run is 11.0402 for case I and 14.5535 for case IV. On the contrary, the more intensive the search behaviour of active customers in the market is, the lower is the price. This can be seen by comparing case III ($\lambda_0 = 0.8$, $\lambda_1 = 0.6$) with case IV ($\lambda_0 = 0.8$, $\lambda_1 = 0.2$). The price at the

[14] The prices are weighted by the market shares of the firms to account for the proportion of a price on the overall level of the price.

[15] A detailed analysis of the moments of the price distributions is given in Table 4.12.

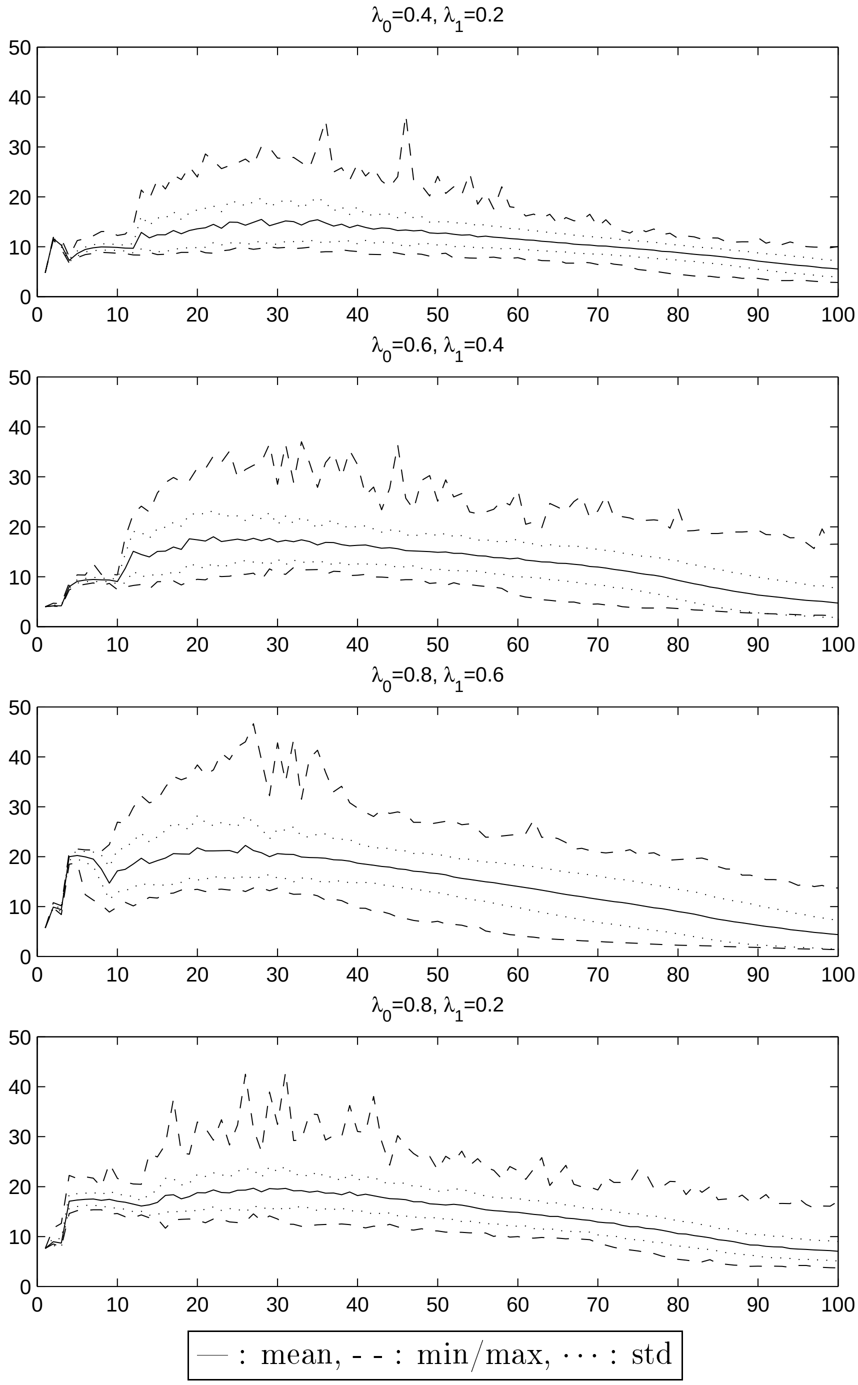


Figure 4.13: Average Price

end of the run ($t = 100$) is 4.3748 for case III and 7.0600 for case IV. When λ_0 and λ_1 increase at the same time, the random effect influences the average price in all periods so that for case I, II, and III the average price is 11.0402, 12.2848 and 14.3798, respectively. The price at the end is 5.5616 (case I), 4.7378 (case II), and 4.3748 (case III). That is, the determination of the price in a certain market depends on λ_0 as well as on λ_1: a high λ_0 increases the average price, whereas a high λ_1 has a negative impact on the average price.

The standard deviation of the prices is the larger the more intensive the search behaviour of all consumers is (both potential and active). λ_1 has the major impact on the standard deviation. As Figure 4.13 shows, the standard deviation for the different markets can be ranked as case III $>$ case II $>$ case I. The standard deviation of case IV lies between those of cases I and II. This means that heterogeneous prices for homogenous products can be observed more likely in a market with high search intensities (low search costs), with the search intensity of the actual customers in particular being of importance. This is surprising, because one would expect a price distribution that is more concentrated in a market with high search intensities. An increase in λ_0 forces the average price up which weakens the effect of λ_1. As the random effect due to λ_0 increases, firms can charge any price they like because the new consumers are less price attentive. Additionally, a high price fluctuation in such markets to keep (attract) customers seems to affect the average price negatively and the divergence of prices positively.

Figure 4.14 shows the empirical price distributions in various periods (three columns: $t = 20$, $t = 60$, and $t = 100$) and for the different constellations of λ_0 and λ_1 (four rows). The capital weighted price density for the different values of λ_0 and λ_1 is given for the beginning, the middle and the end of the simulation runs. The number of variables included in the densities are between 2182 and 7019. This is reported in Table D.1 in Appendix D, p. 192.

All price distributions are strongly skewed to the right. For all constellations of λ_0 and λ_1, the price distributions are becoming more concentrated (i. e. have a higher peak and a lower standard deviation), the longer the market exists (i. e. the larger t is). It is worthwhile noting that the asymmetry still remains despite of the concentration. When t becomes larger, given λ_0 and λ_1 (from the 1st column to the 3rd column), the price distributions move to the left. This means that the

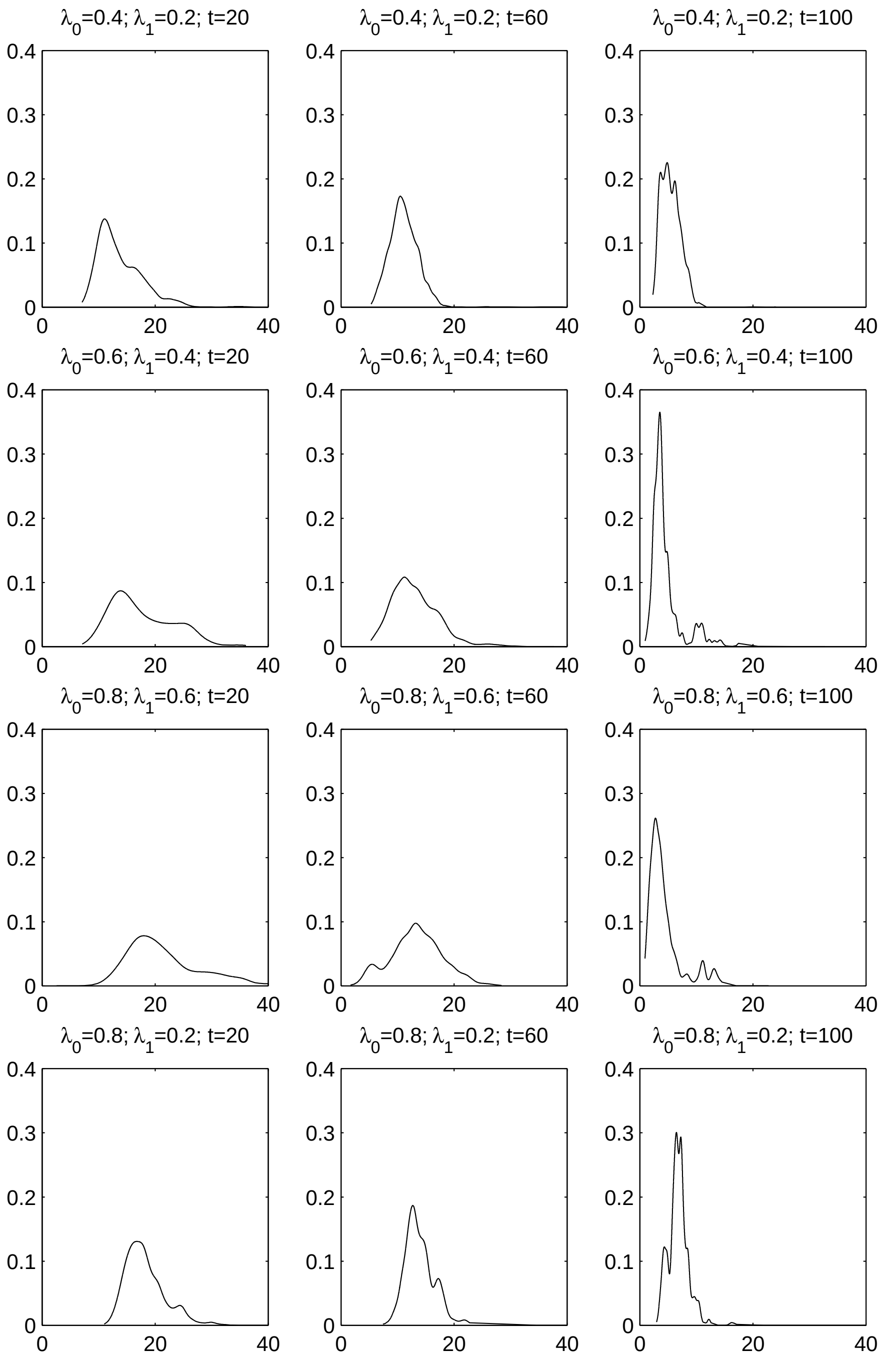


Figure 4.14: Price Distribution

pressure to lower prices will occur. Comparing the four rows, one can observe that in the first two phases an increased λ_1 involves the peak decreasing. The effect that the median and the number of outliers on the right side increases is caused by the increase in λ_0. This effect weakens in phase II. In phase III, λ_0 increases the median only slightly, and λ_1 affects the peak only in the way that it moves to the left. One can conclude that the increased search intensity of active consumers (λ_1) for another supplier who sells cheaper, does not result in a stronger pressure to decrease the price per se. First of all, prices become more dispersed if λ_1 increases. Second, when λ_0 becomes larger, given λ_1, firms tend to charge higher prices because of the randomly matched consumers. Only in the third phase, the price distributions do not change remarkably if λ_0 is increased. But there, a higher search activity of actual customers increases the price competition.

In the literature, it is mostly the lognormal and the Pareto distribution that are proposed as possible distributions for prices and firm-sizes.[16] To test the hypothesis, whether the price distributions fit a Pareto distribution, the Kolmogorov-Smirnov goodness-of-fit test is applied. The null hypothesis is formulated as[17]

$$H_0 : X_i \sim F_0(\cdot),$$

where $F_0(\cdot)$ is any cumulated distribution function that is completely specified and continuous. Here, $F_0(x) = \int_{-\infty}^{x} \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}x} dx$ for the logarithmized prices of the lognormal distribution and $F_0(x) = 1 - (x_0/x)^a I_{(x_0,\infty)}(x)$ for the level prices of the Pareto distribution. The maximum likelihood estimates of the parameters for Pareto distributed random variables are given as[18]

$$\hat{x}_0 = \min_{1<i<n} X_i$$

and

$$\hat{a} = n \left[\sum_{i=1}^{n} \ln(X_i/\hat{x}_0) \right]^{-1}.$$

[16] See e.g. SUTTON (1997) and DOSI et al. (1995).

[17] See e.g. MOOD et al. (1974, p. 508).

[18] See e.g. RINNE (1997, pp. 414).

Under the null hypothesis, the test statistic

$$K_n(X_1, \ldots, X_j, \ldots, X_n) = \sqrt{n} \sup_{-\infty<x<\infty} |F_n(x) - F|$$

of the Kolmogorov-Smirnov goodness-of-fit test is asymptotically approximately distributed as $[1 - 2\sum_{j=1}^{\infty}(-1)^{j-1}e^{-2j^2x^2}]I_{(0,\infty)}(x)$. Critical values for finite samples are tabled.[19] For this case, the critical value at the 95% significance level is $1.3581/\sqrt{n}$, where n is the number of the corresponding random variables (sample size) for each case as given in Table D.1 in Appendix D, page 192.

Table 4.10 shows some statistics and the test results of the empirical price distribution for the lognormal distribution. The mean values of phase I can be ranked as case III (3.0332) $>$ case IV (2.9064) $>$ case II (2.8227) $>$ case I (2.5863). This is due to the random effect by the search activity of the potential consumers, λ_0, as discussed above. In phase II, the differences of the mean values among the markets vanish. This is because of the search effect by the active consumers, λ_1, that only decreases the peak of the density. In phase III, average prices are ranked as case IV (1.8868) $>$ case I (1.6477) $>$ case II (1.8381) $>$ case III (1.2818). As also partly discussed above, the order of the standard deviation is constant from phase I till phase III, namely case III $>$ case II $>$ case I $>$ case IV, despite the changes of the order of the average prices.

The results of the Kolmogorov-Smirnov goodness-of-fit test show that the null hypothesis of a lognormal distribution of the prices can be accepted for almost all of the reported cases. The only exceptions where the test statistic (KS) exceeds its critical value (cv) are the first two phases of case III, where both search intensities are high.

Table 4.11 shows the estimates of the distribution parameters of the Pareto distribution and the results of the Kolmogorov-Smirnov goodness-of-fit test. Interestingly, the parameter of the lower bound of the Pareto distribution, x_0, has the smallest values for the phases I and II of case III, for which the null hypothesis of lognormal distribution had to be rejected. In phase I, case III has the smallest lower bound (2.5474) among all cases, although the average price of case III in phase I is the highest. At the same time, the parameter of tail thickness of the Pareto distribution, a,

[19] See e.g. RINNE (1997, pp. 595).

Table 4.10: Empirical Price Distributions and Kolmogorov-Smirnov Goodness-of-fit Test under the Null of Lognormal Distribution[a]

Phase[b]	Phase I				Phase II				Phase III			
Case	mean	std	KS	cv	mean	std	KS	cv	mean	std	KS	cv
Case I	2.5863	0.2762	0.0010	0.0203	2.3900	0.2429	0.0021	0.0193	1.6477	0.3139	0.0049	0.0162
Case II	2.8227	0.3105	0.0019	0.0241	2.5242	0.3119	0.0015	0.0216	1.3831	0.4844	0.0142	0.0181
Case III	3.0332	0.3031	0.0827	0.0291	2.5238	0.4031	0.0800	0.0229	1.2818	0.5862	0.0044	0.0195
Case IV	2.9064	0.2519	0.0003	0.0221	2.6328	0.2476	0.0014	0.0199	1.8868	0.2824	0.0040	0.0165

[a]KS: Value of the test statistic. cv: Critical value at 95% significance level.
[b]Phases I, I, and III are represented by the periods $t = 20$, $t = 60$, and $t = 100$.

Table 4.11: Empirical Price Distributions and Kolmogorov-Smirnov Goodness-of-fit Test under the Null of Pareto Distribution[a]

Phase[b]	Phase I				Phase II				Phase III			
Case	x_0	a	KS	cv	x_0	a	KS	cv	x_0	a	KS	cv
Case I	7.0584	1.5822	0.0270	0.0203	5.3187	1.3912	0.0301	0.0193	2.2913	1.2216	0.0555	0.0162
Case II	7.0776	1.1550	0.0383	0.0241	5.2800	1.1624	0.0182	0.0216	0.9159	0.6798	0.0210	0.0181
Case III	2.5474	0.4766	0.2339	0.0291	1.6760	0.4982	0.1156	0.0229	0.8900	0.7151	0.0143	0.0195
Case IV	10.9684	1.9555	0.0241	0.0221	7.4191	1.5904	0.0794	0.0199	2.9439	1.2390	0.0318	0.0165

[a]x_0: Minimum of the sample value. a: Tail parameter. KS: Value of the test statistic. cv: Critical value at 95% significance level.
[b]Phases I, I, and III are represented by the periods $t = 20$, $t = 60$, and $t = 100$.

for case III, phase I, is the smallest one among all cases. This means that the tail is relatively thick and, therefore, that the distribution has many outliers, i. e. there are many firms that offer a very high price. This phenomenon shows a high price heterogeneity in a market with high λ_0 and λ_1. The result of the Kolmogorov-Smirnov goodness-of-fit test shows that the null hypothesis of Pareto distribution cannot be accepted for most of the cases. Exceptions are phase II of case II and phase III of case III. This result is not surprising if one looks at the empirical densities in Figure 4.14. The small number of prices that are left on the left of the mode of the density indicates that the distribution is more likely a lognormal than a Pareto distribution.

Table 4.12 summarizes some statistics of the empirical level prices. For all constellations of λ_0 and λ_1, the average prices have the order: phase I $>$ phase II $>$ phase III. The same is valid for the standard deviation. The skewness and the kurtosis do not follow a clear order. Note that the skewness and the kurtosis are very sensitive to outliers and, therefore, few outliers have a decisive influence on their values.

Table 4.12: Statistics of the Empirical Price Distribution

		Moments			
Case	Phase[a]	mean	std	skewness	kurtosis
Case I	Phase I	13.8265	4.2479	1.7116	8.9104
	Phase II	11.2610	3.1875	3.6668	33.4421
	Phase III	5.4570	1.7586	1.4096	12.1874
Case II	Phase I	17.6576	5.5850	0.6738	2.7706
	Phase II	13.1036	4.2014	1.0513	5.1156
	Phase III	4.5506	2.7782	2.2677	9.6835
Case III	Phase I	21.7531	6.9183	1.0781	4.0595
	Phase II	13.3982	4.6210	0.1022	2.9250
	Phase III	4.3332	2.9856	1.7822	5.7880
Case IV	Phase I	19.0895	8.3452	7.3855	73.2292
	Phase II	14.5374	7.0897	9.2347	106.2181
	Phase III	6.9172	3.2184	12.8004	246.3018

[a]Phases I, II, and III are represented by the periods $t = 20$, $t = 60$, and $t = 100$.

That prices decrease on average is induced by the innovative activity of the firms. The decrease of the standard deviation is larger from phase I to phase II than for the transition from phase II to phase III, except for case III. Thus, the dispersion of prices becomes smaller at a higher rate in the last phase of the run. In case III, where the price dispersion decreases faster in the first periods, the pressure on the prices due to high search intensities of both consumer types seems to be higher from the beginning. The decrease of the price dispersion is also affected by a lower bound of the production costs. This can also be observed in Figure 4.13, where in case III the lower bound is reached in first of all cases.

To sum up, the analysis of the price distributions shows that the search activities of the two consumer groups, the potential consumers and the actual customers, have a different effect on the level and the variance of the prices. In the short run, a high search intensity of the potential consumers, λ_0, affects the average price positively. The more a firm expects randomly matched customers, the higher is its incentive to charge a high price. Only a potential consumer is willing to pay any price below his reservation price. An active customer's willingness to pay is strictly lower than his reservation price. In the long run, it is important for firms to maintain a base of customers. As their search intensity, λ_1, increases, the probability that they will buy the next period from a competitor also increases. Therefore, a high search intensity of the actual customers will compel the firms to lower prices. As a consequence of this competition, the average price of a market with high search intensity of the actual customers, λ_1, will be lower than in a market where λ_1 is low. In order to evaluate policy instruments it is important that the time horizon and the state of development of the respective industry be taken into consideration. A policy that aims at improving the consumers' knowledge about firms' prices may easily have a contrary effect if it is applied at the wrong point of time.

4.3.3 Market Structure

In this subsection, characteristics of the industry, such as the number of firms in the industry, rates of entry and exit, the lifetime of firms, the size distribution of firms, the degree of asymmetries among firms, concentration indices, and stability measures for market shares are dealt with. Several measures are applied to analyse the macro pattern that emerges endogenously and that results from the micro behaviour of the agents acting in the observed economic unit as defined by the model equations in Chapter 3.

The major difference between the firm characteristics and the market structure is that the effects of the consumers' activities change remarkably. Concerning the market structure, the actual customers are now most influential, and an effect of potential consumers can only be detected in the short run. This was already observed for the price distribution.

An increase in the search intensity of actual customers, λ_1, causes the price competition to increase so that the probability to survive for firms charging high prices declines. The bankruptcy rate is higher and, therefore, the number of firms in the market is lower. The incentive to enter the market is also lower so that fewer entries occur in a market where actual customers search with high intensity. As a consequence, the concentration of firms, measured as Herfindahl index, is higher. In the short run, there is a high turbulence in market shares that increases in λ_1. In the long run, these turbulences diminish and the firms keep their established market shares. Nevertheless, firms remain heterogeneous, and the distribution of firms is shown to follow the lognormal.

Number of Firms

Figure 4.15 shows the average number of firms (solid line), the minima and maxima (dashed lines), and the standard deviation (dotted lines). After increasing for a short time, the number of firms decreases drastically.[20] This effect is called shakeout and has been observed, for instance, in the automobile industry by ABERNATHY and UTTERBACK (1975). Afterwards, the number of firms increases anew. From case I to case III, the average number of firms decreases to 50.8 (case I) $>$ 40.5 (case II) $>$ 33.7 (case III). The average of case IV is 46.1. The first effect to note is that with increasing λ_1, the number of firms decreases. This is also valid for for the final number of remaining firms, which is 70 (case I) $>$ 56 (case II) $>$ 48 (case III). With a value of 67, case IV is between case I and case II. However, comparing the relative increase in the number of firms from the beginning until the end, the rate

[20] The number of starting firms in each market resulting from the short calibration simulation is 48 (case I), 42 (case II), 30 (case III), and 34 (case IV).

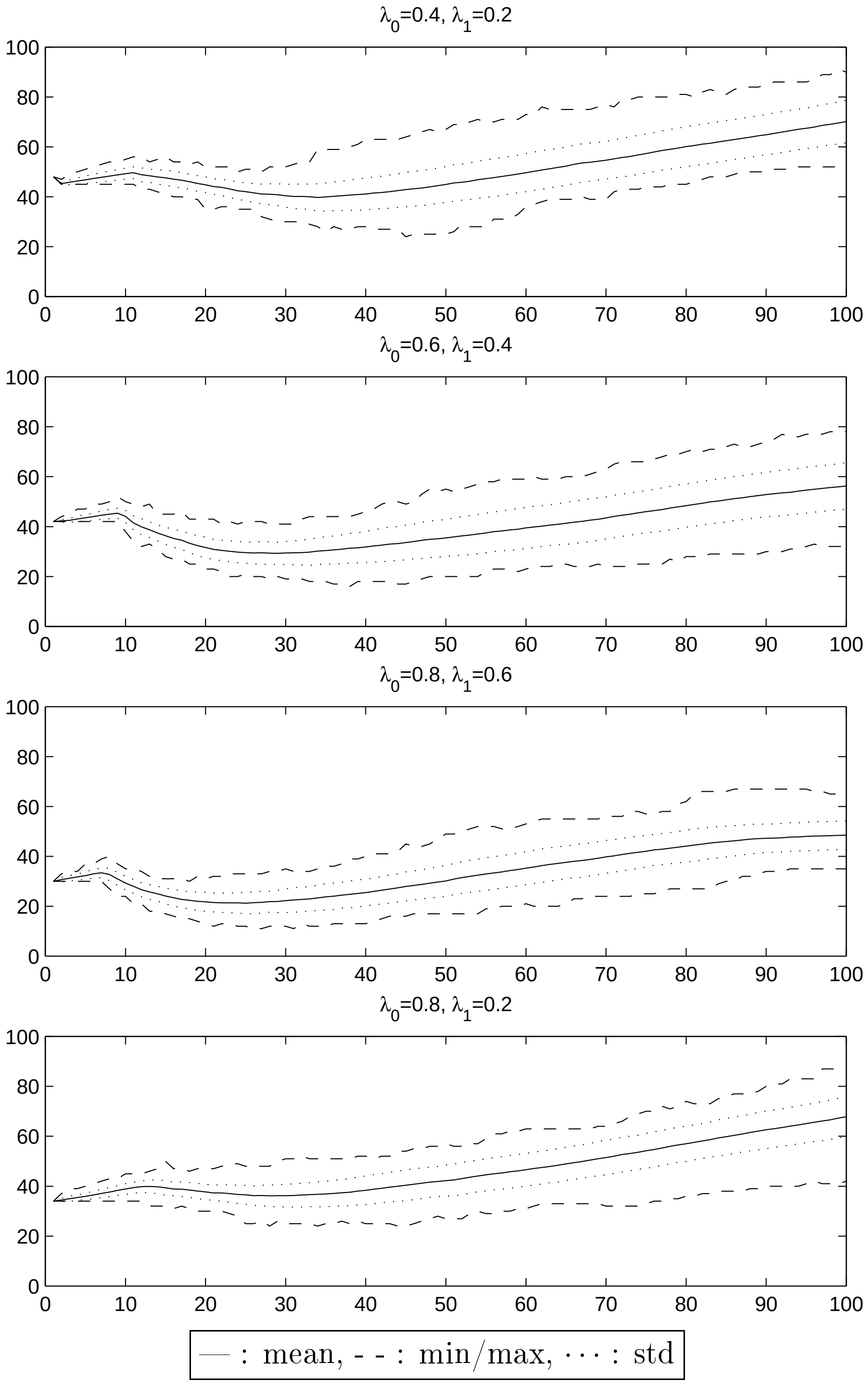


Figure 4.15: Average Number of Firms

of increase amounts to 145% (case I), 134% (case II), 162% (case III), and 199% (case IV). Therefore, one cannot conclude that an increase in the number of firms in a certain market is more or less probable than in other markets. It can, however, be noted that the relative increase in the number of firms is largest in cases III and IV, for high values of the search intensity of the potential consumers, λ_0.

The major determinant of the number of firms appears to be the search intensity of the actual customers, λ_1, whereas the activities of the potential consumers have little effect. This is in line, for instance, with the findings that for high λ_1 the average prices are lower and, as will be demonstrated, the probability to survive is lower if there is hard competition in prices.

Lifetime of Firms

In the early stage of the market the increase in the number of firms is rapidly followed by a shake-out, i. e. a large wave of exits as mentioned above. As a consequence, those firms that enter the market at a later point of time have a lower risk of bankruptcy. Additionally, it is shown that the advantage of a lower risk is accompanied by the disadvantage of a lower performance, i. e. fewer profits.

The lifetime of firms is documented in Figure 4.16 for a single run of case I ($\lambda_0 = 0.4$ and $\lambda_1 = 0.2$). This example shows a typical pattern. On the horizontal axis the number of periods is shown, and on the vertical axis the number of firms. The light grey lines indicate the existence of a firm, the dark grey lines the non-existence before entry (lines beginning from the left) or the time after a previously existing firm had to exit the market (starting after a light grey line).

In the example, the light grey lines in the lower left show that the industry starts with 49 firms. In period 2, three firms have to exit the market. This can be seen by the light grey lines changing their colour to black. The other exits mainly occur between period 10 and 30. Thereafter, it is these firms whose probability to survive is nearly 1, that either have survived until period 40 or entered the market after $t = 30$. The first firm enters the market in period $t = 3$. That is where an initially black line turned into grey. Entries occur in numerous small waves. As for the number of exits only three of the new firms were affected.

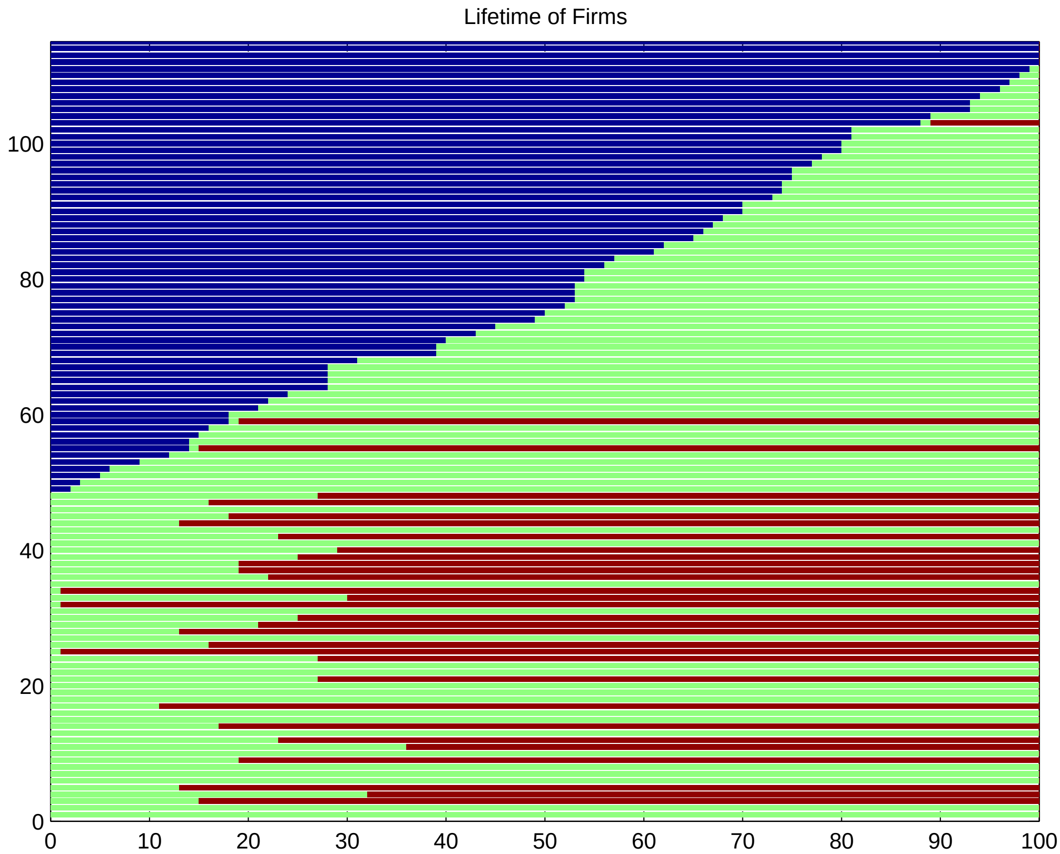


Figure 4.16: Lifetime of Firms ($\lambda_0 = 0.4$; $\lambda_1 = 0.2$)

A detailed analysis of all runs is given in Table 4.13 where the mean and standard deviation of the average lifetime of the firms are reported. Note that the lifetimes of firms cannot be simply compared as they are. Since the lifetime of a firm that enters the market, for instance, in period $t = 90$ can maximally amount to 10 periods, the results would be distorted in the way that firms that enter at a later point of time would have the lowest survival probabilities. In order to see whether there is a significant difference of lifetime between firms which entered the market in the initial period (incumbents) and those firms that entered the market at a later period (entrants), the maximum remaining lifetime has to be taken into consideration. To ensure a fair comparison between the expected lifetime of the two groups (incumbents and entrants), the data which are used are adjusted as follows. Concerning entrants, only those firms are used which have the possibility of surviving for at least

50 periods. Consequently, a firm must have entered at time t, where $1 < t \leq 50$. For the incumbent firms, the maximum time of survival is bounded by 50 periods for each firm. In this way, it is ensured that only those firms are considered which are confronted by the same conditions with respect to the theoretical maximum lifetime.

Table 4.13: Lifetime of Incumbents and Entrants

	Incumbents		Entrants	
Case	mean	std	mean	std
Case I	33.0575	16.5350	47.0342	11.6868
Case II	27.1552	15.5906	47.2532	11.2737
Case III	22.9631	15.6465	47.1583	11.4551
Case IV	37.0415	14.4752	46.9271	11.8819

Table 4.13 shows that for all four cases incumbents have a lower life expectancy than entrants. For the incumbents, the average lifetime, which decreases as the search intensities increase, is given by 33 (case I) $>$ 27 (case II) $>$ 22 (case III). The average lifetime in case IV is 37 periods. This leads to the conclusion that the decrease in average lifetime of incumbents is mainly caused by an increase in the search activity of the actual customers, λ_1. A high search intensity of the potential consumers, λ_0, seems to keep the standard deviation low. The reason is the same as already mentioned above. When actual customers stick to their suppliers (low λ_1) and firms attract many new customers randomly (high λ_0), the probability to survive is high, and firms become more similar, i. e. firm sizes are less dispersed.

Table 4.14 shows the performance (moving average of profits) of incumbents and entrants. Although entrants have a higher probability to survive than the incumbents, their performance is on average lower than the performance of the incumbents in all four cases, and their standard deviation is much higher. For case IV, the means and standard deviations of the performance is similar for the incumbents and the entrants. Concerning performance, both types of firms did best in case III, where λ_0 and λ_1 is high. This is also documented in Figure 4.5.

To sum up, there are advantages and disadvantages for both entry schemes. Entering early secures higher profits at the cost of a lower life expectancy. Entering at a later point of time leads to almost secure life but promises fewer profits. Therefore,

Table 4.14: Performance of Incumbents and Entrants

	Incumbents		Entrants	
Case	mean	std	mean	std
Case I	0.7323	0.2276	0.2799	0.4126
Case II	1.4298	0.5056	1.3709	1.2145
Case III	2.4100	0.5521	1.8884	1.5814
Case IV	1.7355	0.2980	1.7010	0.2889

the entry decision depends on how long the entrepreneur intends to remain in this business. The empirical findings of AGARWAL (1997) indicate that an early entry lowers the initial probability of failure for the firms. This is because the pioneering firms are usually able to reach higher average revenues, particularly in the first market phase. In general it is observed that the hazard rate decreases as a firm becomes older. Because of the competitive pressure generated in the simulation model, the early entrants cannot benefit for many periods if they are unsuccessful in improving their technology. However, it will be shown below that the bankruptcy rate decreases over the course of time for all firms and, that at least in the short run, early entrants can experience larger rates of profitability than in later phases of the market process.

Market Entries

As shown above, the time of entry affects the expected lifetime and the profitability of a firm. How the entry decision observed in the simulation is related to the search intensities and the number of consumers is examined below. It turns out that the incentive to enter the market in the long run depends negatively on the search intensity of the actual customers because a new firm cannot expect a secure customer base.

In Figure 4.17, the solid line represents the number of entries. The number of actual customers per firm is shown by the dotted line. In the left column, the four cases concerning imitative entries are illustrated, and in the right column, the different search cost constellations for innovative entries are given. Note that in Figure 4.17

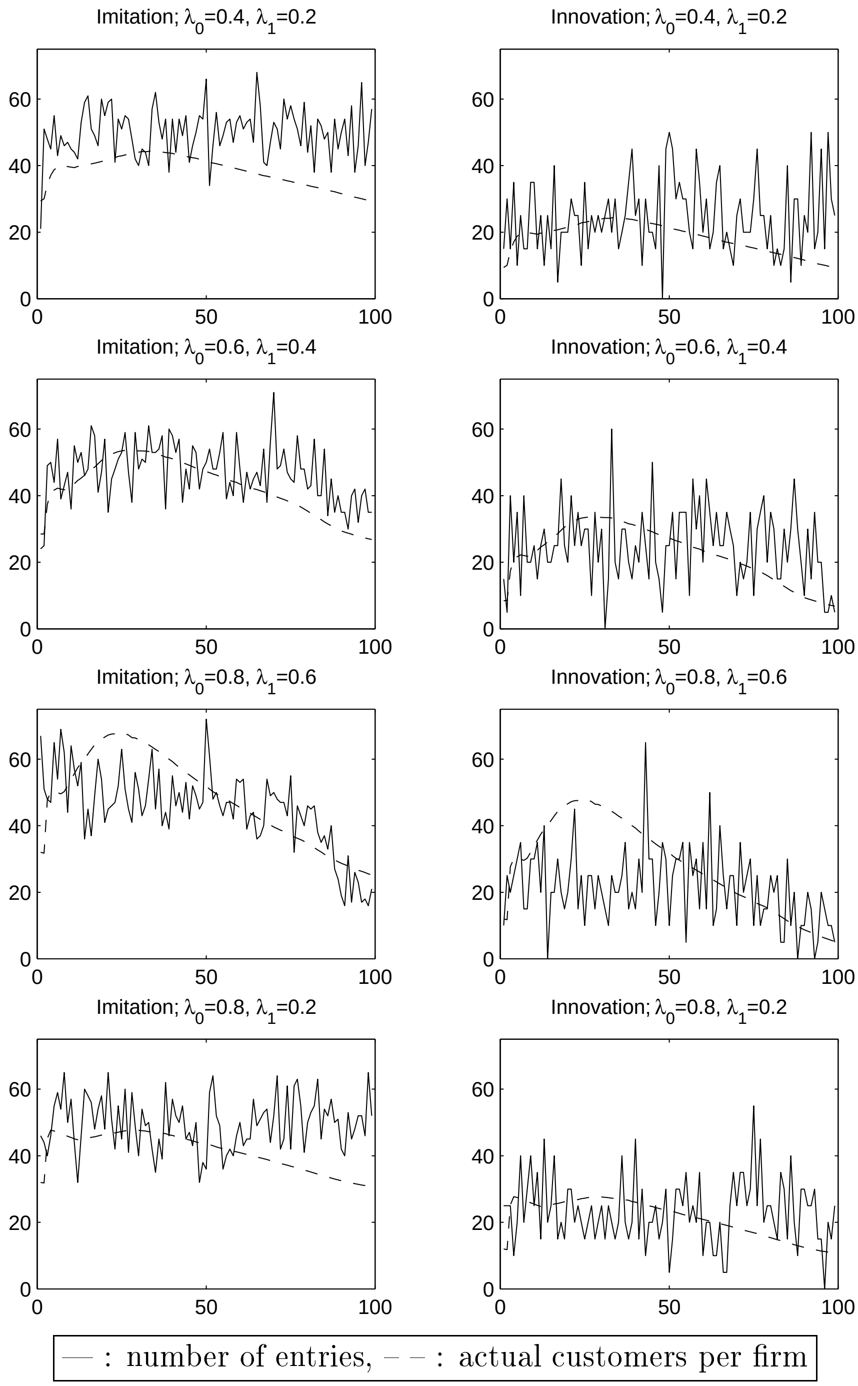


Figure 4.17: Entry Decision and Actual Customers

in the left column the value of the average number of actual customers is shifted by 20 and in the right column the number of innovative entries is multiplied by 5 for better comparison.

Concerning the imitative entries, it appears that the number of entries decreases over the course of time in the cases II and III, where the search intensity of actual customers, λ_1, is high. The decrease of entries in the last phase of the cases II and III is also strongly related to the decrease in the number of actual customers.[21] In cases I and IV, where λ_1 is low, the number of imitative entries seems to be relatively stable for the whole time (regarding the trend). In the case of innovative entries the pattern is similar. In the last phase of cases II and III in particular, entries seem to be positively related to the number of actual customers. As for the quantitative analysis, imitative and innovative entries are analysed together because the correlations between them and the number of actual customers are similar.

Table 4.15 shows the correlation between the number of entries and the number of actual customers in the first column. In the second column the number of imitative and innovative entries occurring on average is reported.

Table 4.15: Correlation between Actual Customers per Firm and Entries: Total[a]

Case	correlation	entries
Case I	0.0981	54
Case II	0.5396	51
Case III	0.5774	49
Case IV	-0.0530	54

[a]The numbers in the first column are the correlation coefficients for the corresponding cases. The numbers in the second column are the average entries for the whole run.

If both search intensities are low (case I), there is only a slight correlation between the number of entries and the number of actual customers. The increase of the correlation coefficient from case I to case III is mainly caused by the increasing

[21]The decrease in demand has already been illustrated in Figure 4.12.

search intensity of the actual customers, λ_1. In case IV, where only the potential consumers search high intensively, there is hardly any correlation. Interestingly, the total number of entries decreases as λ_1 increases. Most entries can be observed in case I and case IV, where the actual customers search with a low intensity. This means that the prospect of a customer base that is very likely to remain at the firm has a positive influence on the number of entries. If actual customers search with low intensity, it neither matters whether there are many actual customers nor whether there are many potential consumers.[22] The firms are less interested in randomly matched consumers than in the possibility of keeping their customer base. If the fluctuation is low (cases I and IV), the number of entries is the biggest. Uncertainty caused by a high search intensity of potential consumers and actual customers (case III) has a negative impact on the number of entries.

Table 4.16 draws a more detailed picture of the correlation between actual customers and the number of entries. The correlation coefficients are shown for the different market phases in the first column, and the average number of entries in the second column. For the single phases, the picture is totally different from the numbers

Table 4.16: Correlation between Customers per Firm and Entries: By Phases[a]

Phase[b]	Phase I		Phase II		Phase III	
Case	corr	entries	corr	entries	corr	entries
Case I	0.2984	17.49	-0.1801	18.87	-0.1028	17.89
Case II	0.5865	17.42	0.2762	17.88	0.7212	16.06
Case III	-0.3834	18.49	0.2417	17.57	0.8859	12.73
Case IV	0.1771	18.39	0.0343	16.81	0.1842	18.67

[a]The numbers in the first column of each phase are the correlation coefficients for the corresponding cases. The numbers in the second column of each phase are the average entries in each phase.
[b]Phases I, II, and III cover the periods $t = 1$ to 33, $t = 34$ to 66, and $t = 67$ to 99.

reported above for the whole run. In phase I, the correlation coefficients are the lowest and the number of entries is the largest for high search intensities of the

[22]This can be concluded because the extent of the correlation between potential consumers and the number of entries is almost the same as that between actual customers and entries, but of the opposite sign.

potential consumers, λ_0, i. e. in cases III and IV. There is only a slight correlation in case IV, and in case III, the correlation is even negative. The highest correlation is obtained in the medium case II, where both search intensities are neither high nor low. Extracting different effects of λ_0 and λ_1 is difficult although it seems that λ_0 has a negative impact on the correlation coefficients of phase I. In phase II, all correlation coefficients are relatively low. In case IV there is no correlation at all. The highest correlation still can be found in the medium case II. In phase II, the correlation seems to be positively influenced by λ_1. The number of entries is the largest in case I, where both search intensities are low. The lowest number of entries occurs in case IV. The number of entries seems to be negatively influenced by high uncertainty due to the random effect of λ_0, regardless of the number of actual customers. The stable environment (case I) is characterized by a slightly negative correlation between entries and the number of actual customers. This means that the entrants do not expect to attract customers from the incumbents because the latter are very likely to keep their customers. In the cases II and III, where the actual customers are more willing to change their supplier, an entrant is more likely to attract some of these customers by offering a lower price. In phase III, the negative correlation between actual customers and the number of entries remains negative. The correlation increases drastically from case I to cases II and III, where all consumers search intensively. The low search intensity of case IV seems to have the expected negative impact on the correlation although the coefficient remains positive.

The absolute number of entries differs slightly in all cases of the first two market phases. In phase I, most entries occur in the cases III and IV, where λ_0 is high. Phase II is characterized by the lowest number of entries. Whereas phase I lacks a clear structure, phase II shows a tendency towards a negative impact of λ_0 on the average number of entries. In phase III, the differences become clearer. From case I to case III the number of entries decreases steadily. In case IV there are many entrants, so that in the last phase the low search intensity of the actual customers seems to play the key role in inducing entries. Concerning the entry of new firms, these results corroborate the findings above that the timing of entry plays an important role for the development of firms.

Market Exits

Figure 4.18 illustrates the bankruptcy rates for the different constellations of search intensities. Table 4.17 summarizes the bankruptcy rates for the different cases divided into three phases. After a first phase of adjustment, there is a span of time of about 30 periods, where the level of exiting firms is considerably high compared to later periods. In cases I and IV, where λ_1 is low, the rate of exit is the lowest. In cases II and III, the bankruptcy rate is higher for a high search intensity of actual customers, λ_1. The search intensity of the potential consumers, λ_0, has only a slightly positive impact on the standard deviation.

As discussed with respect to the lifetime of the firms above, Figure 4.18 shows that the bankruptcy rate mainly depends on the search intensity of the actual customers, λ_1. The average bankruptcy rate is relatively low for low values of λ_1, i. e. in the cases I and IV. As λ_1 increases, the bankruptcy rate increases, i. e. the order of the average bankruptcy rate is: case III (0.0398) $>$ case II (0.0274) $>$ case I (0.0177). The average bankruptcy rate of case IV amounts to 0.0248. Additionally, λ_1 seems to influence negatively the span of time until the bankruptcy rate becomes relatively stable.

The picture becomes more differentiated when the three phases are analysed separately as given in Table 4.17. For all cases the bankruptcy rate decreases from phase I to phase III. The decrease from phase I to phase II is larger than the decrease from

Table 4.17: Bankruptcy Rate

Phase[a] / Case	Phase I	Phase II	Phase III
Case I	0.0246	0.0155	0.0131
Case II	0.0372	0.0241	0.0211
Case III	0.0615	0.0323	0.0262
Case IV	0.0291	0.0242	0.0211

[a]Phases I, II, and III cover the periods $t = 1$ to 33, $t = 34$ to 66, and $t = 67$ to 99.

phase II to phase III in all cases. This means that the main adjustment takes place

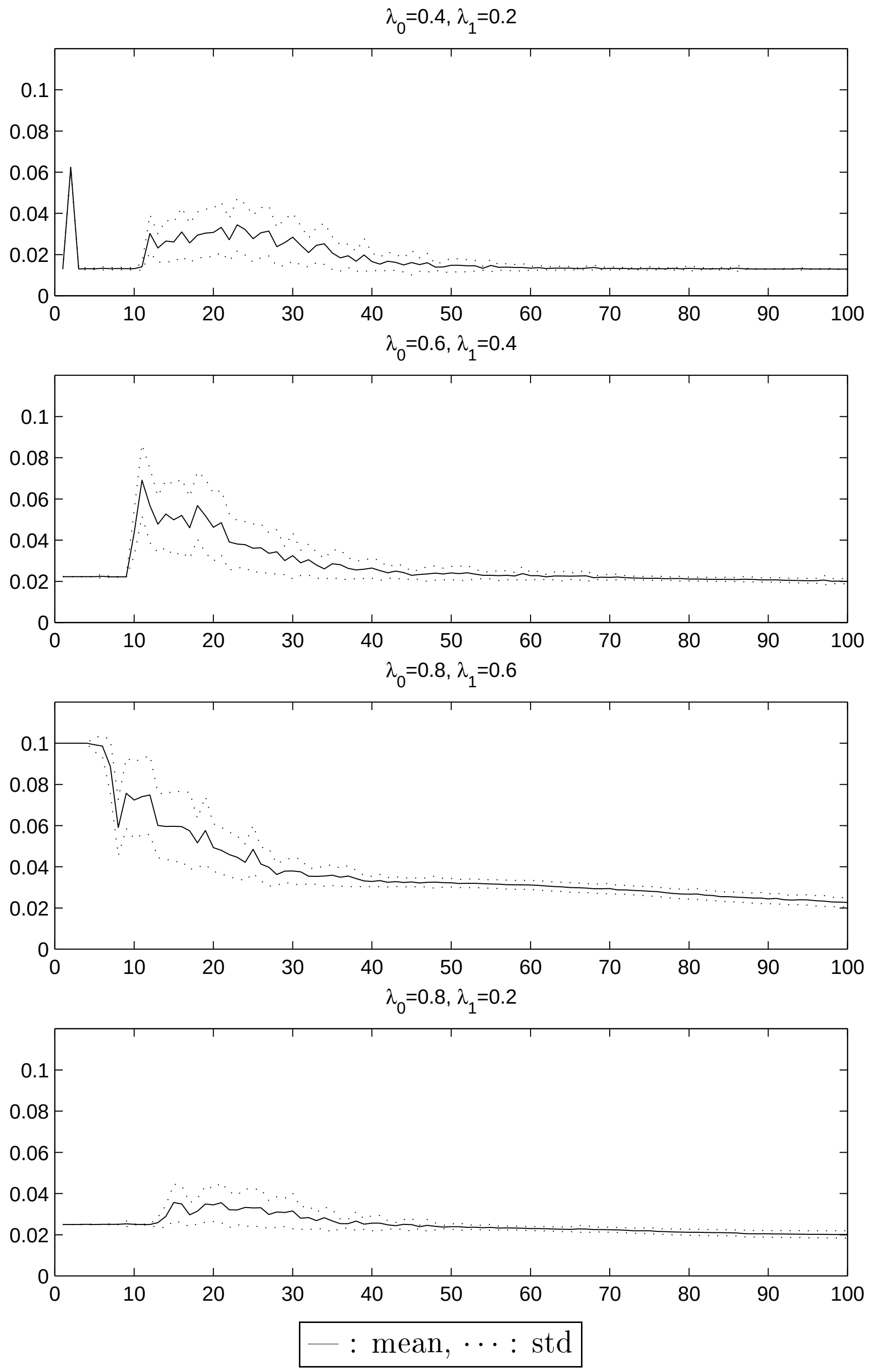


Figure 4.18: Bankruptcy Rate

during the first two market phases. In the third market phase, exits occur only at a low rate. In all phases, the bankruptcy rate is the lowest where λ_1 is low, and it increases as λ_0 and λ_1 increase. Comparing case III with case IV shows that the low λ_1 in case IV keeps the bankruptcy rate lower than in case III. As the bankruptcy rate of case IV in each phase is higher than in case I, it can be concluded, that the bankruptcy rate also increases in λ_0. The negative impact of λ_0 on the bankruptcy rate in the phases II and III is stronger than in phase I. This is probably caused by the strong adjustment process of the bankruptcy rate during the first 10 periods in each case.

Concentration and Stability

In this section, the impact of the consumers' search behaviour on the competitive structure of the industry is studied. A measure for concentration which is widely used is the Herfindahl index. Here, a stability index is applied in addition to the Herfindahl index to capture also the dynamics in market shares. This is necessary because it is impossible to conclude merely from a high concentration index whether there is competition (e. g. oligopolistic price competition) or not (e. g. a cartel).

The existence of concentration indices is the result of studying how "to summarize the distribution of market shares among firms in a single index to be used in econometric and antitrust analysis."[23] The most popular measure that is mentioned, for instance, in TIROLE (1988) is the Herfindahl index. The Herfindahl index is defined as sum of the squared market shares of all firms.[24] It is a static measure that should be employed in relationship to the profitability of firms. As pointed out by MAZZUCATO (2000) and even further emphasized by DAVIES and GEROSKI (1997) it is important that changes in market shares be analysed, which is particularly true for the leading firms. The (in-)stability of market shares can be viewed as a measure for competitiveness, whereas it is impossible to gain many insights into the underlying competitive forces by analysing a concentration index only. Examining empirical data for several industries for the years 1979–1986, DAVIES and GEROSKI (1997) found highly varying market shares within the group of the top-five firms.

[23]See TIROLE (1988, p. 221).

[24]For empirical studies, SCHMALENSEE (1989, p. 966) suggests to use concentration ratios as alternative because they are widely published.

Compared to the turbulence in market shares, concentration changed slowly. They conclude that concentration and competitiveness are two distinct characteristics of an industry which are hardly related. Further, their estimations give rise to believe that R&D and innovations affect the dynamics of market shares as well as concentration to a great extent. That a high innovation intensity may cause concentration to decline is shown, for instance, by Mukhopadhyay (1985) and Audretsch (1997).

According to the above-mentioned items concerning market structure, this section is divided into three parts. First, the firm-size distributions are studied. Second, concentration indices, namely the Herfindahl index and the Lorenz curve are calculated, and profitability is measured. Thirdly, a stability index is analysed.

1. Firm-size Distribution.

   According to Sutton (1997), firm-size distributions are often similar to Yule, Pareto, or lognormal distributions. It is demonstrated that the distributions obtained by this simulation fit well to the lognormal distribution. Results for different search intensities are compared.

   The distributions of firm size are shown in Figure 4.19. The peak of the density (mode) moves to the right from phase I to phase II for all cases. In phase III, the mode turns back to the left for all cases. Interestingly, for the cases II and III, the movement of the mode to the right is followed by it turning back more drastically than in the cases I and IV. Thus, the random effect of the potential consumers is dominant in the cases I and IV. In the cases II and III, the search activity of the active consumers plays a more important role. Therefore, the average capital stock increases more moderately if customers are more price attentive. The same is valid for the asymmetry, i. e. the distributions become more and more right-skewed in cases II and III as time passes, whereas in cases I and IV the distributions are almost symmetric in phase III. The skewness to the right means that intensively searching actual customers involve some firms to be successful with their capital accumulation (because they are rewarded by a large customer base when charging low prices). This does not apply to the markets I and IV, where the random effect dominates. The peak of the density appears to be lowest in phase II. This can be explained by the fact

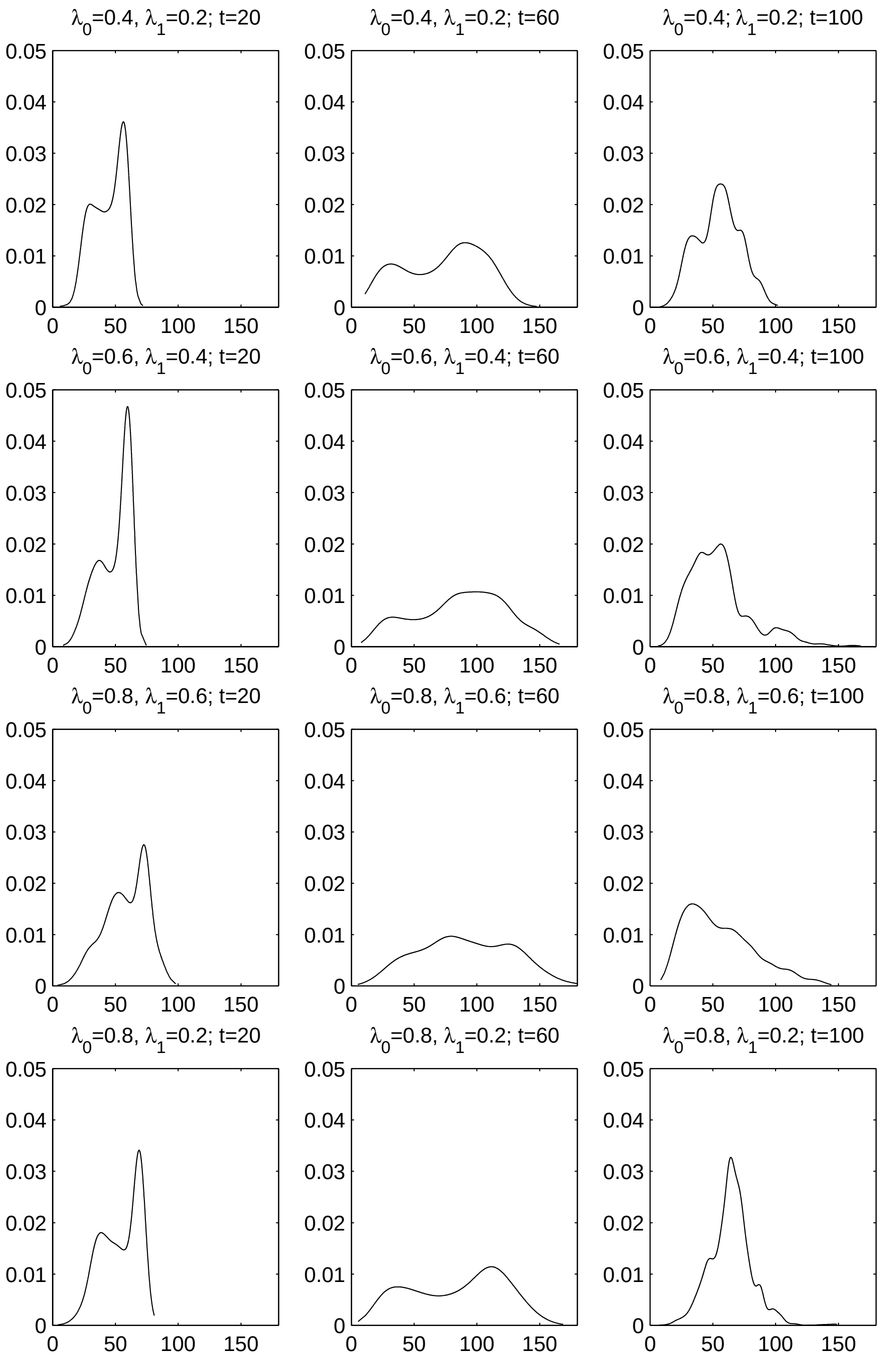


Figure 4.19: Firm-size Distribution

that in phase II the capital accumulation diverges because of differences in the adjustment of firms.

As documented in Table 4.18 (on page 149), the mean becomes higher from phase I to phase II and decreases from phase II to phase III for all cases. As shown in Figure 4.19, this is directly related to the movement of the distributions. The means in phase I cannot be clearly arranged. However, in phase II the means of cases II and III (4.3526 and 4.4124) are higher than those of cases I and IV (4.1704 and 4.3027). In phase III the relations change so that the means of cases I and IV (3.9414 and 4.1283) are higher than those of cases II and III (3.9129 and 3.8983). This suggests that in the end, the average capital accumulation depends more strongly on the search intensity of the actual customers, λ_1, than on the search intensity of the potential consumers, λ_0.

The standard deviation for case III increases monotonically from phase I to phase III. For cases I and IV the standard deviation first increases and thereafter decreases. The same is valid for case II. The decrease from phase II to phase III is not as distinct as the decrease of cases I and IV. This means that in a market where the search intensity of actual customers, λ_1, is high, the capital accumulation can diverge considerably.

Table 4.18 shows the results of the Kolmogorov-Smirnov goodness-of-fit test for the lognormal distribution. In Table 4.19, the results of the Kolmogorov-Smirnov goodness-of-fit test for the Pareto distribution are presented. The null hypothesis of lognormal distribution cannot be rejected for most of the cases at the significance level of 95 per cent.[25] Exceptions are the phases I and II of case III. On the contrary, the null hypothesis of Pareto distribution cannot be accepted at the 95 per cent level for any case. This is not surprising because it can easily be verified in Figure 4.19 that a great deal of the probability mass is on the left of the mode in all distributions. Because of outliers, the lower bound x_0 shows no clear system with respect to λ_0 or λ_1. The estimates of the parameter of tail thickness, a, increase from phase I to phase III for most of the cases. This indicates that there are some firms with a disproportionately large capital stock (outliers).

[25] H_0 is rejected if the test statistic (KS) exceeds its critical value (cv).

Table 4.18: Empirical Firm-size Distributions and Kolmogorov-Smirnov Goodness-of-fit Test under the Null of Lognormal Distribution[a]

Phase[b]	Phase I				Phase II				Phase III			
Case	mean	std	KS	cv	mean	std	KS	cv	mean	std	KS	cv
Case I	3.7485	0.3262	0.0010	0.0203	4.1704	0.5501	0.0021	0.0193	3.9414	0.3542	0.0049	0.0162
Case II	3.8530	0.3179	0.0019	0.0241	4.3526	0.5228	0.0015	0.0216	3.9129	0.4409	0.0142	0.0181
Case III	4.0124	0.3597	0.0827	0.0291	4.4124	0.4844	0.0800	0.0229	3.8983	0.5129	0.0044	0.0195
Case IV	3.9363	0.3327	0.0003	0.0221	4.3027	0.5585	0.0014	0.0199	4.1283	0.2801	0.0040	0.0165

[a] x_0: Minimum of the sample value. a: Tail parameter. KS: Value of the test statistic. cv: Critical value at the 95% significance level.
[b] Phases I, I, and III are represented by the periods $t = 20$, $t = 60$, and $t = 100$.

Table 4.19: Empirical Firm-size Distributions and Kolmogorov-Smirnov Goodness-of-fit Test under the Null of Pareto Distribution[a]

Phase[b]	Phase I				Phase II				Phase III			
Case	x_0	a	KS	cv	x_0	a	KS	cv	x_0	a	KS	cv
Case I	5.7765	0.5013	0.0787	0.0203	10.8402	0.5596	0.0505	0.0193	7.8882	0.5330	0.1207	0.0162
Case II	8.3063	0.5760	0.1723	0.0241	7.7307	0.4334	0.1374	0.0216	6.2200	0.4796	0.1286	0.0181
Case III	3.6685	0.3686	0.1903	0.0291	5.0656	0.3584	0.1029	0.0229	8.3530	0.5632	0.0819	0.0195
Case IV	3.8831	0.3876	0.2234	0.0221	5.2666	0.3786	0.2403	0.0199	7.0710	0.4603	0.1652	0.0165

[a] x_0: Minimum of the sample value. a: Tail parameter. KS: Value of the test statistic. cv: Critical value at the 95% significance level.
[b] Phases I, I, and III are represented by the periods $t = 20$, $t = 60$, and $t = 100$.

The results of the Kolmogorov-Smirnov goodness-of-fit test are unambiguous. For the data of the simulation model, firms will be distributed according to a lognormal distribution, which corresponds to the findings of many empirical studies. Empirical evidence has also been found for the Pareto distribution. It seems to be of secondary importance which type of distribution emerges. It is more important to find out the forces that induce a skewed distribution allowing for outliers. Obviously, the simulation model is capable to reconstruct this stylized fact. A possible impact on the type of distribution may have the constraint by the required minimum efficient scale. Firms below the critical size have to exit the market. This lower bound implies a tendency towards the lognormal and away from the Pareto distribution.

In Table 4.20 is shown how the firm size is related to the number of actual customers and to the profits for all cases, where three phases are distinguished. For each phase, the left column contains the correlation coefficient between firm size and actual customers. In the second column, the correlation coefficients between firm size and profits are reported.

Table 4.20: Correlation Between Firm Size and Number of Customers and Firm Size and Profits

Phase[a]	Phase I		Phase II		Phase III	
Case	customers	profits	customers	profits	customers	profits
Case I	0.7637	0.6281	0.7893	0.3791	0.5874	0.3154
Case II	0.5662	0.6127	0.7067	0.5164	0.6281	0.4558
Case III	0.5216	0.5709	0.5363	0.4907	0.4144	0.5087
Case IV	0.7154	0.7354	0.8582	0.5362	0.7026	0.4195

[a]Phases I, II, and III are represented by the periods $t = 20$, $t = 60$, and $t = 100$.

Table 4.20 reveals a clearly positive correlation between the average size of the firms and the total number of active customers. In the market phases I and II, the correlation between firm size and the number of customers is higher for low values of λ_1 (cases I and IV). There, the customers stay longer at the same firm than in cases II and III. As a consequence, a firm with a large customer base is able to grow, since it is also shown in the table that in cases I and IV the firm size is highly correlated with profits in phase I. In phase II, the correlation between the number of customers and the firm size is even higher for the cases I and IV, where the search intensity of the actual customers is low. The correlation between firm size and profits has decreased, where the decrease is larger for cases I and IV with a low λ_1. In phase III, the correlation between customers and firm size decreases for all cases, where the highest correlation can still be found in case IV. Not only do the firms have a relatively stable number of patronizing customers, they also have numerous new customers who are randomly distributed. Except for case III, all the correlation coefficients between firm size and profits have reached their lowest level in phase III. Firms grow faster if they can keep their patronizing customers easily and if, additionally, there are many consumers in the market whom they can attract from their competitors.

2. Concentration Indices.

The **Herfindahl index** is a standard measure of concentration of firms in a market. It is defined as[26]

$$H_t = \sum_{i \in \mathcal{Z}_t} s_{it}^2,$$

where s_{it} is the market share of firm i at time t. In the case of a monopoly, the Herfindahl index is equal to one. When additional firms enter the market, the index decreases. The reciprocal value of the Herfindahl index measures the number of firms that are in the market under the assumption that all firms are of the same size. Figure 4.20 illustrates the development of the Herfindahl index in the four markets.

The Herfindahl index increases in all four cases over the course of time. Except for case III, where both groups of consumers search with a high intensity, the concentration declines in phase III. λ_1 seems to have the main influence on the shape of the concentration index. Starting from approximately the same levels, an increase in the index can be observed in all cases up to a certain period. If case I (0.0505) is compared to case IV (0.0654), in period

[26] See e.g. Tirole (1988, pp. 221).

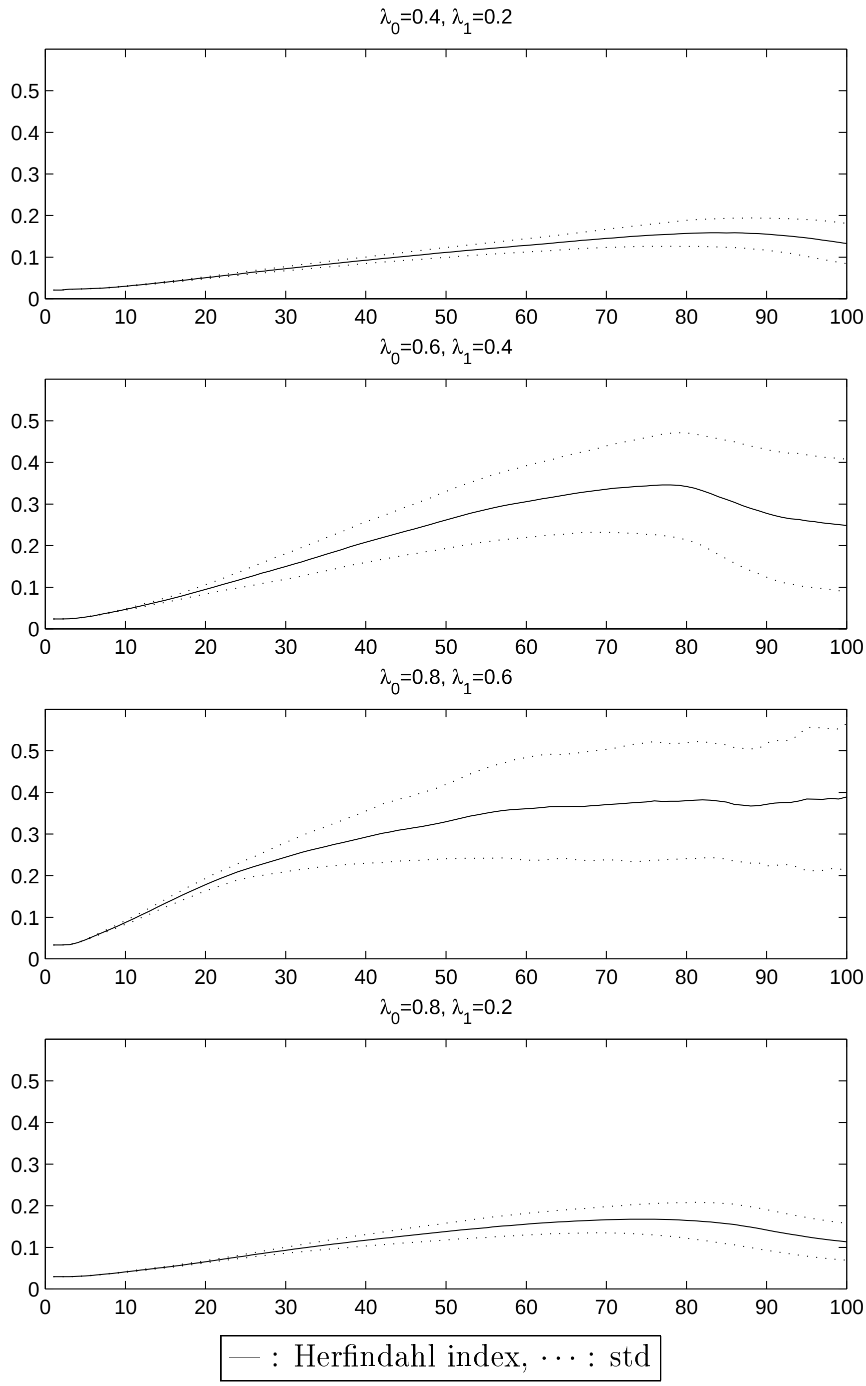


Figure 4.20: Herfindahl Index

$t = 20$, the increase is relatively moderate and varies only slightly due to the different search intensities of potential consumers, λ_0. The increase due to λ_1 is stronger, the higher the search intensity of actual customers, λ_1, is: case I (0.0505) < case II (0.0948) < case III (0.1782) in period $t = 20$. The increase in the Herfindahl index is even stronger in period $t = 60$. There, it is case I (0.1284) < case II (0.3057) < case III (0.3606), and case IV (0.1556) in the domain of case I. In the last phase of the run, namely from about $t = 75$ on, the concentration index slows down in all four cases. At the end of the run ($t = 100$), the different markets end up with an index that amounts to case I (0.1325) < case II (0.2485) < case III (0.3891), and case IV (0.1134) similar to case I. Cases I ($\lambda_0 = 0.4$, $\lambda_1 = 0.2$) and IV ($\lambda_0 = 0.8$, $\lambda_1 = 0.2$) differ in the development of the concentration measure. In case IV the index increases faster, and the values are above those of case I up to the maximum. When the index falls, in case IV the decline is faster than in case I so that in the end of the run, case IV < case I. On average, the index of case IV (0.1159) is larger than in case I (0.1027). According to the influence of λ_1, the order of the markets is: case I (0.1027) < case II (0.2169) < case III (0.2844). Therefore, one can conclude that according to the Herfindahl index, a market is the more concentrated the higher the search intensity of the actual customers, λ_1, is.

The **Lorenz curve** is another possibility of illustrating the concentration. For the concentration of firm size and profits, the Lorenz curves are shown in Figures 4.21 and 4.22. For the presentation of the Lorenz curve a typical run is chosen. The solid line represents the concentration for the period $t = 20$. The dashed line stands for $t = 60$, and the dotted line for $t = 100$.

The concentration of capital shown in Figure 4.21 can be approximately ranked as phase II > phase I > phase III for all cases. Only for case III, where λ_1 is relatively high, the concentration of capital in phase III is approximately equal to the concentration in phase I. This result is empirically plausible. In the early phase of the market development, the accumulation of capital diverges, whereas in later market phases the accumulation of capital tends to converge in the cross-sectional data.

The Lorenz curves for the profits are shown in Figure 4.22. The concentration of profits can be ranked as phase III > phase I > phase II. Only for case

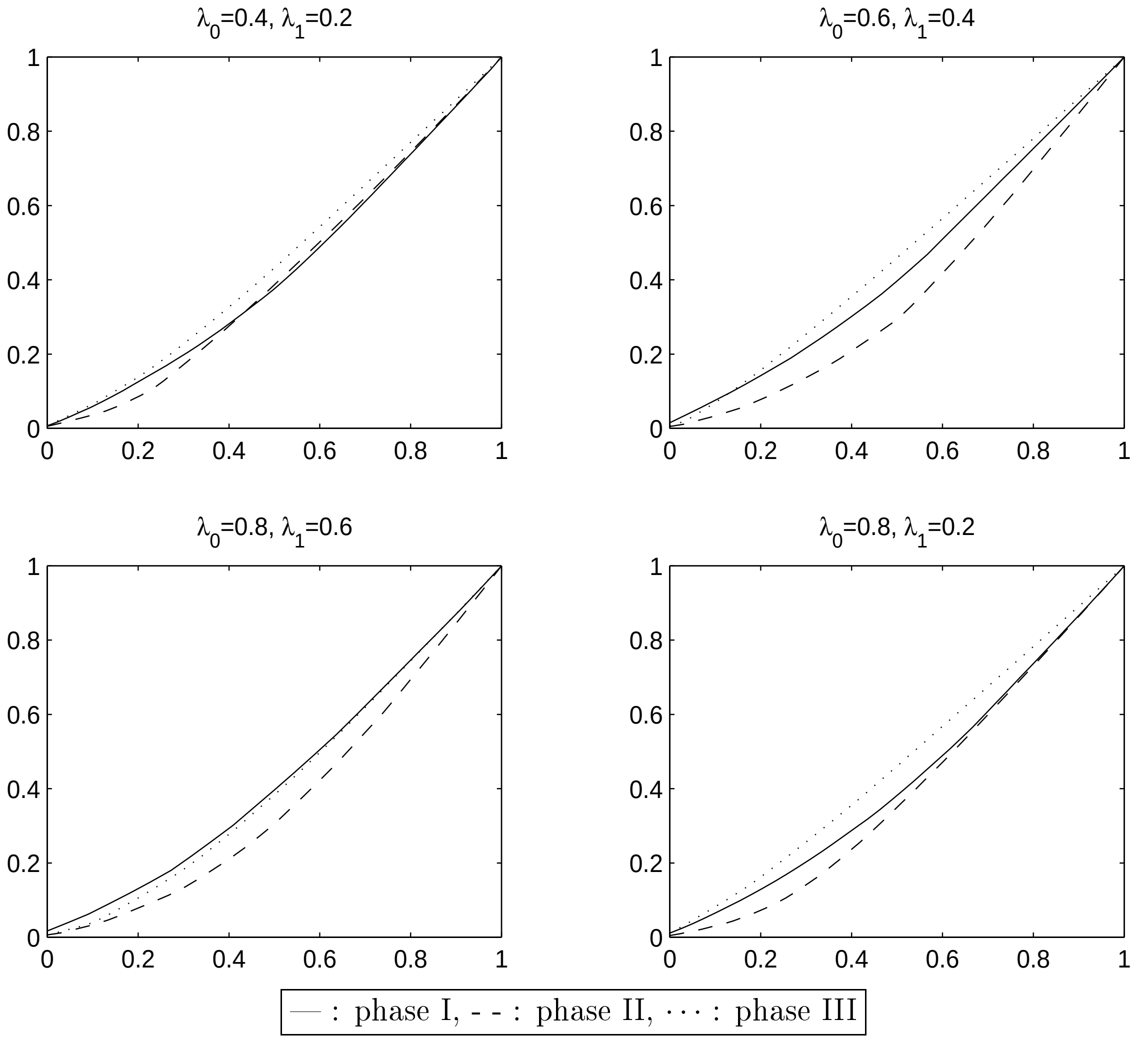
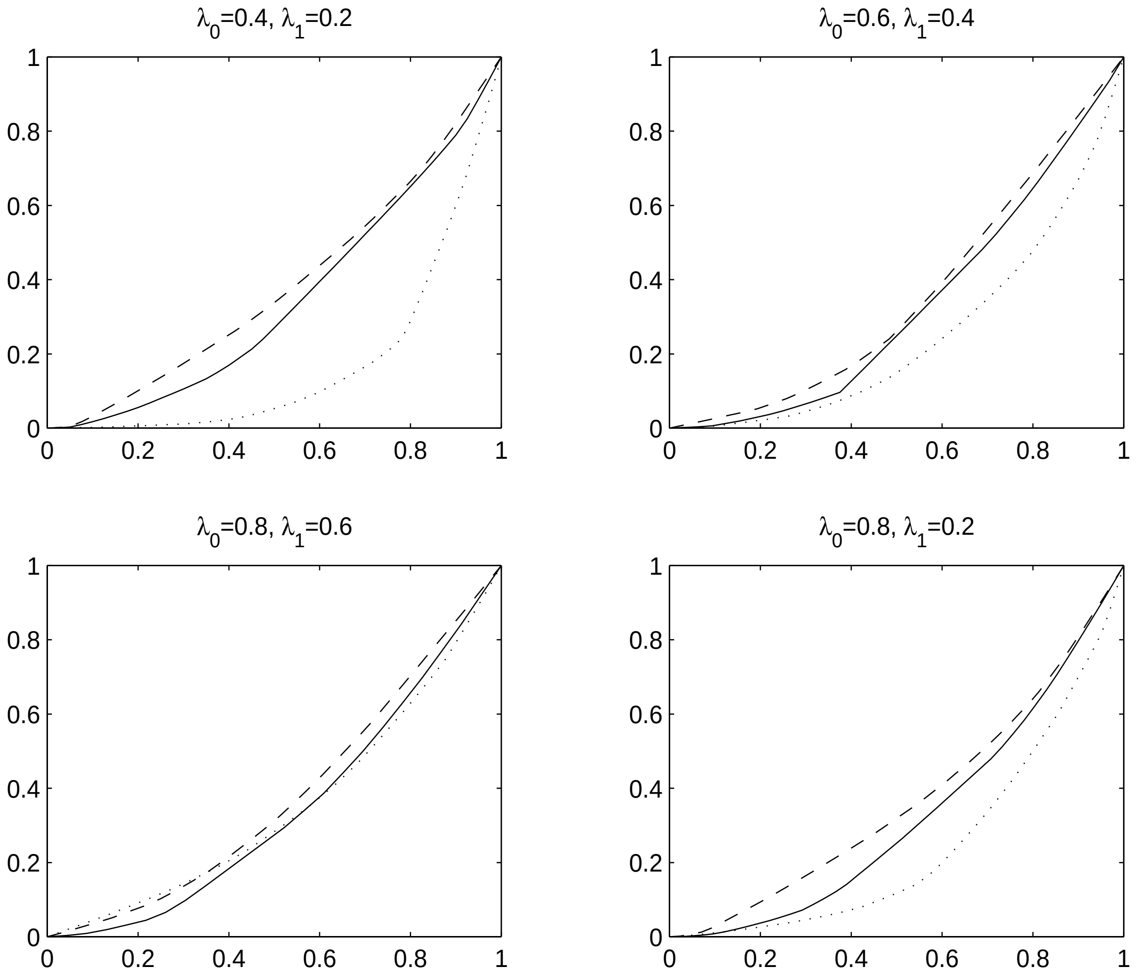


Figure 4.21: Lorenz Curve for Capital

III, where λ_1 is relatively high, the concentration of profits in phase III is approximately the same as in phase I. This means that in a market with a moderate search intensity of actual customers, λ_1, the concentration of profits is high. When the actual customers have a high search intensity as in case III, the concentration of profits remains low.

Interestingly, in Figure 4.21 and Figure 4.22, the concentration of profits moves opposite the concentration of firm size. Therefore, the inverse relation indicates that it is worthwhile analysing the market structure in more detail.



— : phase I, - - : phase II, ··· : phase III

Figure 4.22: Lorenz Curve for Profits

SCHMALENSEE (1989, p. 988) reports as stylized fact that "[i]n cross-section comparisons involving markets in the same industry, seller concentration is positively related to the level of price." If the average prices, reported in Table 4.10, are compared to the concentration index, the findings of SCHMALENSEE (1989), that the level of the price follows the same pattern as the Herfindahl index of market concentration can be confirmed for the first two market phases in the "normal" cases I, II, and III. In phase III, the relationship between the price level and concentration is reciprocal. The average price is higher if the concentration is low.

To substantiate the analysis of the concentration, in addition to the Herfindahl index, the **profitability** of firms is studied. In the short run, the price-cost margin is used to analyse the market power of a firm. The higher the price-cost margin, the more is the price above marginal costs, i. e., the higher is the monopoly power of a firm. In the long run, not only do the profits have to cover variable costs, they also have to cover the fixed costs. These are mainly costs concerning the capital stock, i. e. interest and depreciation. Therefore, the price markup is set in relation to the long-run average costs. According to SCHMALENSEE (1989, pp. 960), in a competitive market it must hold that the price equals average costs, i. e.

$$\frac{P_{it} - c_{it} - (\rho + \delta) \cdot \frac{K_{it}}{Q_{it}}}{P_{it}} = 0, \tag{4.1}$$

where P_{it} is the price of firm i in in period t, c_{it} are the variable production costs, K_{it} is the capital stock, Q_{it} is the output produced, ρ is the interest rate, and δ is the rate of depreciation.

The price-cost margin (PCM) is defined as

$$\text{PCM} := \frac{P_{it} \cdot Q_{it} - c_{it} \cdot Q_{it}}{P_{it} \cdot Q_{it}},$$

i. e. as the difference of revenues and variable cost in proportion to the revenues. Under competitive conditions the PCM should equal the required rental on assets employed per monetary unit of sales (RRA) on average. Using Equation (4.1), the RRA is defined as

$$\text{RRA} := (\rho + \delta) \cdot \frac{K_{it}}{P_{it} \cdot Q_{it}}.$$

In the long run, the PCM alone does not contain the relevant information because a price above marginal costs does not imply positive profits. Compared to the RRA, a firm has the more monopoly power, the bigger the difference

Table 4.21: Profitability of Firms[a]

Case	Phase[b] / Firms[c]	Phase I PCM-RRA	Phase II PCM-RRA	Phase III PCM-RRA
Case I	Small	3.8417	2.4038	2.0694
	Medium	3.1119	1.4572	1.1359
	Large	0.8617	-0.2585	-0.2152
Case II	Small	4.9054	4.5832	3.9021
	Medium	3.3867	1.6430	1.6702
	Large	0.0660	-0.5659	-0.5344
Case III	Small	5.7628	5.7624	5.4732
	Medium	3.0150	1.3565	1.6352
	Large	-0.1612	-0.6910	-0.6474
Case IV	Small	6.4576	4.0834	3.2047
	Medium	5.3559	2.3959	1.3661
	Large	1.2891	0.0127	-0.1102

[a]PCM: Price-cost margin; RRA: Required rental on assets.
[b]Phases I, II, and III cover the periods $t = 1$ to 33, $t = 34$ to 66, and $t = 67$ to 99.
[c]For simplicity, to distinguish between small, medium and large firms, the total number of firms has been equally divided into three parts.

between the PCM and the RRA is. The results are summarized in Table 4.21.[27]

It is noticeable that for all cases in all phases small firms have the highest profitability, measured by the difference between PCM and RRA. Medium-sized firms are less profitable than small firms. The worst profitability is obtained by the large firms, which in some cases even cannot cover their long-run average costs, i. e. their profitability is negative. The difference between the PCM and the RRA decreases from phase I to phase III for the small and medium-sized firms in almost all cases. In all cases, the rate of the decrease is higher for the medium-sized firms than for small firms. For the large firms,

[27]The single values for the PCM and the RRA are reported in Table D.2, Appendix D, p. 192.

profitability decreases from phase I to phase II. In phase III it usually exceeds the level of phase II.

Concerning the influence of the search activities of the consumers, the picture is mixed. In phase I, the profitability of the small, medium-sized, and large firms depends positively on the search activities of the potential consumers, λ_0. The medium-sized firms are also slightly negatively influenced by the search activities of the actual customers, λ_1. This negative impact of λ_1 is even stronger for large firms. In phase II, λ_0 still has a positive effect on the profitability of all firms. The negative impact of λ_1 on the profitability of medium-sized firms has strengthened. On the contrary, the profitability of the small firms seems to be positively influenced by λ_1. In phase III, the dominating effect for the small firms becomes λ_1. Medium-sized firms are additional to the positive impact of λ_0 slightly positively influenced by λ_1. Only for the large firms nothing has changed over the whole time.

The small firms seem to have the most advantages over the other firms if the search intensity of the potential consumers, λ_0, is high, i. e. in cases III and IV. Due to their small scale, small firms can sell the whole amount that was produced to randomly matched consumers. For the large firms it is important that customers be kept. Therefore, the large firms obtain the best results in cases I and IV, where λ_1 is low. Large firms (have to) offer lower prices on average.

The absolute values of the PCM and the RRA are documented in Table D.2, Appendix D, p. 192. It shows that the absolute value of the price-cost-margin in most cases and phases is the largest for small firms and the lowest for large firms. The medium-sized firms usually achieve a price-cost margin that lies between the PCM of the small and large firms. This is in line with the analysis of the growth rates, the profits, and the demand-supply ratio related to firm size above. Competition increases for all firms over the course of time, but remains harder for large firms than for small and medium-sized firms. This effect is the stronger, the higher the search intensity of actual customers, λ_1, is.

3. STABILITY INDEX.

   Consumers' surplus is used as measure for how well a market works and is affected when prices change. High prices and high concentration indicate a low consumers' surplus, which in turn signals high profitability and, therefore, low competitiveness. For example, TIROLE (1988, pp. 222) mentions that concentration and profitability are positively related in an industry. In many models negative relations between concentration and welfare have been found. As main conclusion TIROLE (1988, p. 223) states that "[c]oncentration indices are useful in that they give an easily computable and interpretable indication of how competitive the industry is." This statement is thwarted by the analysis of DAVIES and GEROSKI (1997). They show that in the U. K. from 1979 till 1986 there were hardly any relations between the stability of market shares and the change in concentration. Not only did they observe the concentration ratios, they also found out that although the concentration ratios remained relatively stable there was much competition among the leading firms. This was deduced from changing market shares and positions of the leading firms. Therefore, one cannot simply draw a conclusion on the competitiveness of a market by only looking at a concentration index. Furthermore, over the life cycle of an industry many relationships will change. Evidence for the turbulence in market shares is, for instance, provided by DAVIES and GEROSKI (1997), AUDRETSCH (1997), and concerning the life cycle of an industry by ABERNATHY and UTTERBACK (1975), KLEPPER (1996, 1997), and AGARWAL (1997). They show that even in a highly concentrated industry the competition between the firms, particularly the leading firms, can be hard. AUDRETSCH (1997) also finds that in entrepreneurial technological regimes the turbulence tends to be high.

   Since the concentration measures analysed above are static, they only provide information about the distribution of firm size in the industry. They do not allow conclusions on the competitiveness. MAZZUCATO (2000, p. 14) states that "[s]ince it is possible to have two industries with identical concentration ratios but very different instability indices, and since stability suggests the presence of collusion, the instability index captures an important aspect of competition." The instability index is proposed by HYMER and PASHIGIAN (1962).

They argue that, for instance, the analysis of the change in rank of the leading firms, the so-called turnover measure, does not capture any economically interesting information. Particularly if firm size is not equally distributed, the measure contains no information at all. To measure the competitiveness of the industry, HYMER and PASHIGIAN (1962) use the change in market share over the course of time. Market shares are used instead of ranks because a market share is always related to the size of the market and can therefore provide information about the development of the market. The stability index they propose is defined as

$$I = \sum_{i \in \mathcal{Z}_t} (|s_{it} - s_{i,t-1}|) ,$$

where s_{it} and $s_{i,t-1}$ are the market shares of firm i in period t and $t-1$, respectively. $\mathcal{Z}_t$ is the set of active firms in period t. The stability index measures directly the change in all market shares. The index increases with the number of firms included. If it is assumed that the additional firms are small, the measure is not affected to a great extent. Moreover, this index assumes that the growth rate of firms of different sizes is weighted equally. To account for the different absolute values of capital accumulation they suggest to use the market share at the beginning of each period as weight. This leads to the following modified stability index:

$$I = \sum_{i \in \mathcal{Z}_t} (|s_{it} - s_{i,t-1}|) \cdot s_{i,t-1}. \tag{4.2}$$

Since in the simulation model the growth rates of small firms are usually larger than those of large firms, the modified stability index as given in Equation (4.2) is applied to account for these difference. The results are shown in Figure 4.23.

In the beginning, the effects of an adjustment process are visible. The stability index is very volatile and its movement becomes smoother from period $t = 10$ on. In all four cases, the stability decreases in tendency, where particularly in the first market phase there is some turbulence in the index.

The level of the stability index[28] varies in the four cases. On average, the lowest level is obtained in case I (0.3458) $<$ case II (0.4477) $<$ case III (0.5140). The

[28] The values are multiplied by 1000.

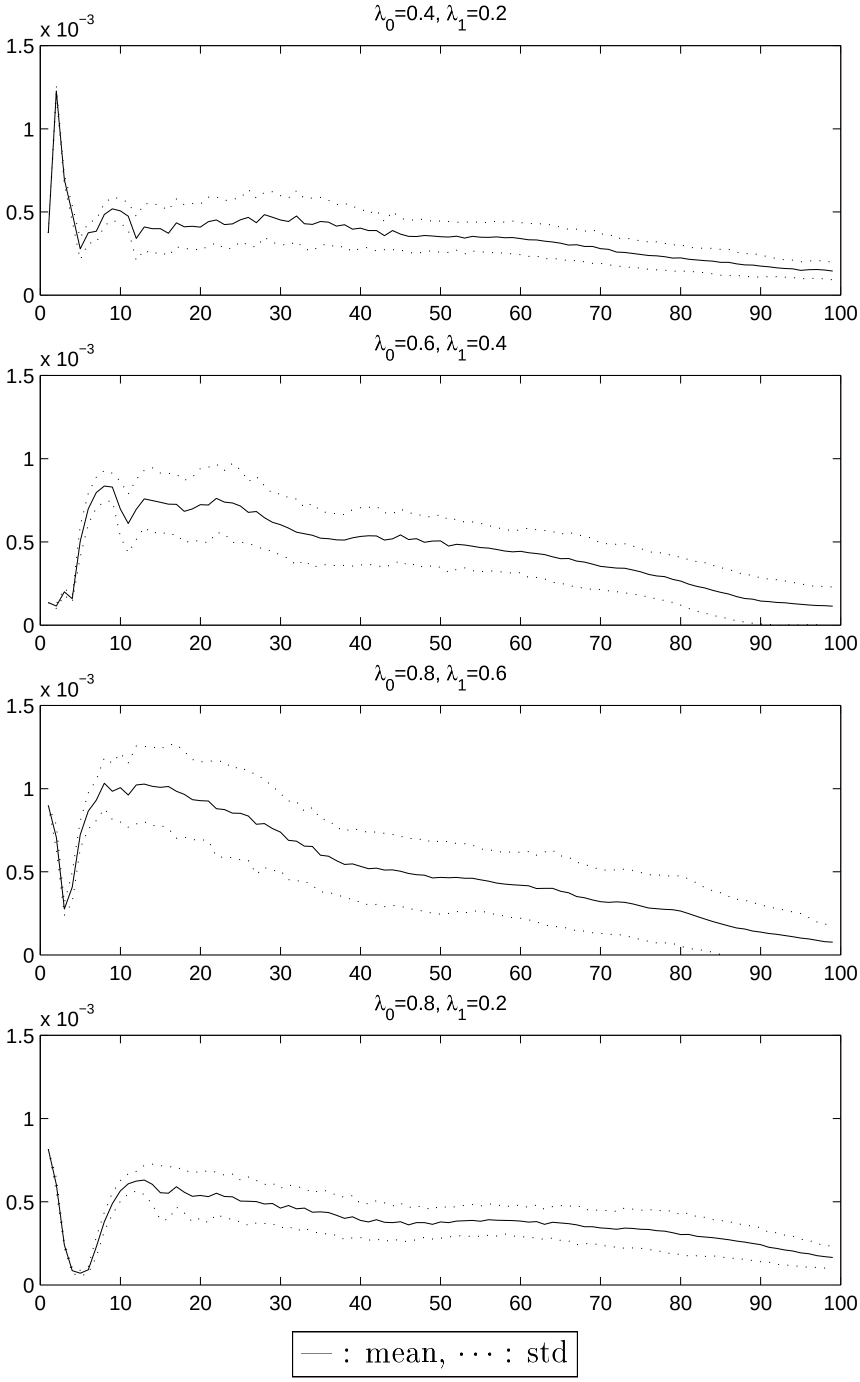


Figure 4.23: Stability Index

mean of case IV is 0.3820 and lies in the range of case I. Therefore, a clear positive impact of the search intensity of the actual customers, λ_1, on the average stability in the market can be observed.

The means of the stability index are divided into the three market phases are presented in Table 4.22. In phase I the order remains the same as for the means of the index. That is, the index is mainly positively influenced by λ_1. In phase II, the lowest values are still obtained in cases I and IV, where λ_1 is lowest. In cases II and III the values are similar. The influence of λ_1 has decreased, but a stronger effect of the search intensity of the potential consumers, λ_0, cannot be found. In phase III there are obtained similar values for almost all cases. Only in case IV it is noticeable that the big difference between λ_0 and λ_1 seems to increase the instability in that market.

Table 4.22: Stability Index[a]

Phase[b] / Case	Phase I	Phase II	Phase III
Case I	0.4623	0.3638	0.2112
Case II	0.6266	0.4842	0.2324
Case III	0.8489	0.4790	0.2139
Case IV	0.4803	0.3874	0.2783

[a]The values are multiplied by 1000.
[b]Phases I, II, and III cover the periods $t = 1$ to 33, $t = 34$ to 66, and $t = 67$ to 99.

4.4 Summary

The analysis of the data shows that the development of the simulated industry depends on the search activities of the consumers, with the search intensities of the potential consumers and the actual customers playing different roles.

Concerning first the firm characteristics, a general pattern is evident. For most of the variables, i. e. the firm size, profits and performance, investment, and R&D expenditures, the search intensity of the potential consumers, λ_0, affects the level of the means, whereas the search intensity of the actual customers, λ_1, accounts for its variability. It is for the above-mentioned variables that an increase of the mean is generally followed by its decrease. The higher λ_0 is, the higher is the mean. The standard deviation is high for high λ_1. It is only for the profits and the performance that the standard deviation decreases over the course of time. The higher the random effect caused by a high search intensity of the potential consumers, the higher are on average both the capital stock and the profits of the firms. Investment in capital as well as expenditures on R&D also increase on average if the actual customers tend to remain loyal to their firm. The main reason why intensively searching actual customers widen the differences among firms seems to be that the pressure exerted on firms is relatively high, which prevents firms from performing well in competition.

If the actual customers search with low intensity, firms engage in keeping their customers and attracting customers from their competitors in order to create a basis for (further) growth. Therefore, the average expenditures on R&D increase in λ_1. Interestingly, if the search intensity of the actual customers, λ_1, is high, the number of imitations and innovations is lower than if λ_1 is low, i. e. despite higher expenditures, the absolute number of imitations and innovations as well as the cost reduction induced by the usage of new technologies are lower. For all constellations of λ_0 and λ_1, the average production costs decrease steadily. Although there is no obvious influence of the search intensities, the lower bound of the production costs is reached earlier if λ_1 is low.

Moreover, the analysis shows that small firms grow faster and invest a larger amount of money per unit of capital than large firms. Small firms also have higher expenditures on R&D per unit of capital. R&D expenditures (total and per unit of capital) are slightly negatively correlated with firm size, and from phase II on they are negatively correlated with profits. Small firms adjust more quickly to the demand conditions than large firms. Large firms are generally characterized by an excess supply. If the search intensity of the actual customers is high, the adjustment process is faster.

Prices react differently on both search activities, depending on the phase of time. Interestingly, the average prices increase during the first phase and decrease only after some time has passed. The standard deviation remains relatively constant and is higher for large values of λ_0. In the phases I and II, a high average price is mainly caused by λ_0, whereas in the last phase, the average price depends negatively on λ_1.

If attention is turned to the market structure, the influence of both search intensities varies. The number of firms in the market depends negatively on λ_1, and the standard deviation is slightly negatively related to λ_0. The number of entries depends on the time horizon: in the short run, i. e. in the first phase, the number of entries is higher for high λ_0. In the long run, the negative influence of λ_1 is predominant. The bankruptcy rate decreases in all cases over the course of time and is larger on average where λ_1 is large. Concerning the expected lifetime of firms, firms that enter the market at a later point of time live longer on average than the incumbents but have a lower performance.

The firm-size distribution that emerges from the simulation is lognormal. A low search intensity of the actual customers, λ_1, appears to be the most important parameter to support the growth of firms. The asymmetric firm-size distribution is accompanied by a steadily increasing Herfindahl index of concentration in the market. The concentration is positively affected by a high search intensity of the actual customers, λ_1. Comparing the Herfindahl index with the stability index shows that the concentration corresponds to market power indeed. In the first phase, the stability index is relatively high, and the market shares exhibit some turbulence. Over the course of time, however, the stability index decreases as the Herfindahl index increases. This means that the market shares are relatively stable so that a high concentration index is equivalent to low competition among firms. In the short run, the stability index is positively affected by λ_1.

Most of the stylized facts mentioned in the beginning can be reproduced by the simulation data. The concentration increases over the course of time, and the market shares become more stable. The firm-size distribution is asymmetric and fits well to a lognormal distribution. An advantage of firm size in R&D cannot be found, and the stylized facts concerning the life-cycle hypothesis cannot all be confirmed, as predicted for homogeneous goods. The number of entries is steadily increasing and, therefore, the number of firms in the market is quite high. Nevertheless, it is evident that the difference made between potential consumers and actual customers is of utmost importance.

Finally, the conclusion drawn in simple static search models that high search costs lead necessarily to a high market price cannot be sustained in the evolutionary framework. Instead, one has to distinguish carefully between the search intensities of potential consumers and actual customers. Furthermore, one has also to take into account the respective market phase because the effects of the search behaviour of both groups depend on the development of the industry with respect to its life cycle.

A cynic is a man who loves the price of everything and the value of nothing.

Oscar Wilde (1854–1900)

Chapter 5

Conclusion

The aim of this thesis was to demonstrate that consumers' behaviour has a decisive impact on the innovative behaviour of firms and on the development of industry. As a framework, the evolutionary simulation model of Winter (1984) was chosen. This is one of those models that follow the Schumpeterian approach and that are capable of capturing important features underlying the process of economic change. Compared to the orthodox neoclassical models concerning technological change, the evolutionary approach has several advantages. First, it operates without constructing a steady state. Consequently, many constraining assumptions that ensure the existence of an equilibrium can be abandoned. Second, one can do without the controversial assumption of rational expectations. Third, it allows for heterogeneous economic agents instead of one representative agent. Finally, the evolutionary approach allows to analyse processes in real time and, hence, offers an explanation for the mechanisms of the driving forces of economic change.

The major change performed in this thesis is to extend the focus of an evolutionary simulation model towards regarding the economy as a whole. Not only is economic progress contingent on innovative firms, it also depends on the behaviour of consumers. In contrast to the orthodox market model, consumers are imperfectly informed and have to engage in costly search for a supplier. Equally, firms cannot be sure to sell all their goods. Hence, firms must engage in cost reducing activities, i. e. in R&D, to generate process innovations or to imitate a production technique of a competitor, which helps keeping the output price low and gaining customers. This process is ongoing because consumers never stop searching. Those who have already found a supplier will change him as soon as they have received a cheaper offer.

The main results obtained from the simulation are as follows. First, it has been shown that consumers' behaviour influences firm characteristics and R&D strategies. This aspect was completely neglected in the models of Nelson and Winter (1982) and Winter (1984). Furthermore, it is necessary that a distinction be made between those consumers who search for the first time and those who have already found a supplier. If this simulation had been performed using a common search model, these effects could not have been detected because search processes would have stopped as soon as a consumer had found a supplier. The results obtained here justify the effort to implement the sophisticated approach of Bontemps et al. (2000) into the evolutionary simulation model of Winter (1984).

The analysis of the data has revealed that the search activities of the two groups of consumers, i. e. potential consumers and actual customers, have various effects. First, their influence on the variables differs. Concerning prices, for instance, there is a short-run effect of the search activities of the potential consumers and a long-run effect of the actual customers, whereas production costs are hardly correlated with consumers' search behaviour. Second, the effects have different patterns with respect to the microeconomic and macroeconomic development. The level of the firm-specific data mainly depends on the search intensity of the potential consumers, whereas the search intensity of the actual customers affects the heterogeneity among firms. As for the market structure, one should expect that high search intensities lead to a competitive market, and low search intensities involve more concentration and less competition. The results, however, show that it is mainly the search intensity of the actual customers that has an impact on the development of the market structure. A high search intensity of the actual customers implies few firms and a relatively high stability index, suggesting severe turbulence in market shares although the Herfindahl index of concentration is high. R&D expenditures are higher, but generate less useful results than in situations where the actual customers search less. The effect of the search intensities on the price distribution changes over the course of time. In the first phase of the life cycle, the random effect, which results from a high search intensity of the potential consumers, causes the average price to increase. When the industry matures, actual customers who search very intensively are able to compel the firms to lower prices. Moreover, the results indicate that the firm-size distributions as well as the price distributions are stable and fit well to the lognormal distribution.

The conclusion of this analysis is that in general there is a complex relationship between the information of the two groups of consumers, the average price, and the innovation intensity. The question whether a large amount of information on behalf of consumers improves welfare or leads to a higher growth rate has to be answered carefully. Since a potential consumer is assumed to buy at the first firm that offers a price below his reservation price, the average price is high, provided that potential consumers have low search costs. As no firm offers a price above consumers' reservation prices, potential consumers are distributed equally among firms. Firms thus will sell a certain number of goods regardless of the prices they charge, which, indubitably, involves the average price tending to be high if there are many potential consumers. According to the industry life cycle, the aggregate demand decreases as industry matures, which implies that firms have to be more attentive to patronizing customers. Therefore, by the time when the market is satiated, consumers have been provided with more market power so that the search activities of actual customers in particular compel firms to lower prices.

On closer examination there is not only a possibly welfare-improving effect of lower prices in the long run if consumers are better informed. Regarding the expenditures on R&D and the extent of innovations and imitations, a trade-off can be noticed between search costs and economic change. If the search costs of the actual customers are relatively low, i. e. if they search very intensively, hard competition forces the expenditures on R&D up, but the results obtained by imitations and innovations are less effective than in situations in which the search intensity is low. Therefore, one should keep in mind that high search costs have a positive effect on technological progress, which in turn enables firms to lower prices. Nevertheless, one should not draw the conclusion that only ignorant consumers enhance technological progress.

Concerning policy issues, the results are ambiguous. Unlike common studies that do not take the effects of consumers' behaviour on industrial development into account, this thesis shows that consumer protection is a complex issue. First, if the quality of information was to be improved, it is important that a distinction between potential consumers and actual customers be made. Second, the effects of information depend on the time of its provision. Since the impact of a policy that aims at providing more information to consumers cannot be predicted with certainty, it is advisable not to intervene into the economic process.

Appendix A

Flow Chart

The flow chart shown in Figure A.1 outlines the functioning of the simulation model. The processes are presented in their logical order. This is not always the same as in the programme code because of technical reasons. The figure is shown on the next page.

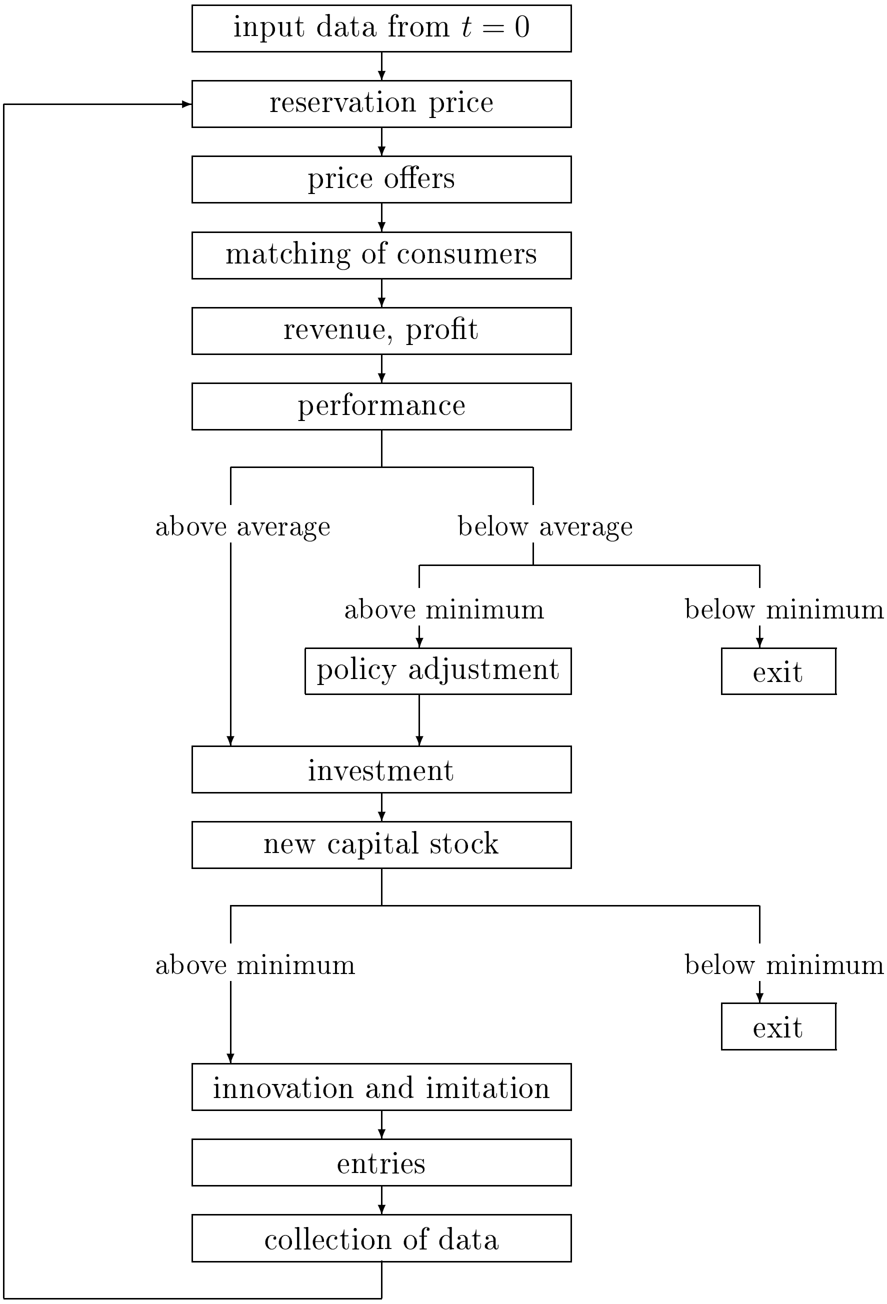


Figure A.1: Program Plan

Appendix B

Variables and Values

Consumers		
$\boldsymbol{N}$	1000	number of consumers
$\boldsymbol{E_t}$	$E_0 = 360$	actual customers
$\boldsymbol{U_t}$	$U_0 = 640$	potential consumers
$\boldsymbol{\lambda_0}$		search intensity of U
$\boldsymbol{\lambda_1}$		search intensity of E
$\boldsymbol{\varphi_t}$		reservation price
$\boldsymbol{b}$	$1.5 \cdot (gmax + \rho + \delta + rm + rn)$	income index
Firms		
General		
$\boldsymbol{Z_t}$	$Z_0 = 30$	number of firms
$\boldsymbol{\mathcal{Z}_t}$		index set
$\boldsymbol{K_{it}}$	$K_{i,0} = 24$	capital stock
$\boldsymbol{K^{\min}}$	15	
$\boldsymbol{A}$	0.5	productivity
$\boldsymbol{Q_{it}}$	$= A \cdot K_{i,t}$	output
$\boldsymbol{Q_t}$	$= \sum_{i \in \mathcal{Z}_t} Q_{it}$	industry output
$\boldsymbol{P_{it}}$	$= l^{-1}(Q_{it})$	price
$\boldsymbol{\bar{P}_t}$		average price
$\boldsymbol{F_{P_t}}$		price offer distribution
$\boldsymbol{\gamma_{it}}$	$\gamma_{i,0} \in [0.1; 0.2]$	variable production cost

$\boldsymbol{c_{it}}$	$c_{i,1} = \gamma + \rho + \delta$	production cost
$\boldsymbol{\rho}$	0.015	return on capital
$\boldsymbol{\delta}$	0.03	depreciation rate
$\boldsymbol{q_{it}}$		quantity sold
$\boldsymbol{\pi_{it}}$		profit
$\boldsymbol{X_{it}}$	$X_{i,1} = 0$	performance
$\boldsymbol{X_{it}^{\min}}$		critical performance level
$\boldsymbol{\zeta_t}$	$\zeta_0 = 0.025$	bankruptcy rate
Investment		
$\boldsymbol{I_{it}}$		investment per unit of capital
$\boldsymbol{I_{D_{it}}}$		desirable investment
$\boldsymbol{I_{F_{it}}}$		financeable investment
R&D		
$\boldsymbol{r_{it}^m}$	$r_{i,1}^m = 0.002$	R&D policy
$\boldsymbol{r_{it}^n}$	$r_{i,1}^n = 0.005$	R&D policy
$\boldsymbol{\bar{r}_t^m}$		average R&D policy
$\boldsymbol{\bar{r}_t^n}$		average R&D policy
$\boldsymbol{L_t}$	$L_0 = 0.16,\ L_1 = L_0 \cdot g_L^t$	latent knowledge
$\boldsymbol{g_L}$	0.99	growth rate of L_t
$\boldsymbol{d_{it}^m}$	$\text{Prob}[d_{it}^m = 1] = a^m \cdot r_{it}^m \cdot K_{it}$	binomial
$\boldsymbol{d_{it}^n}$	$\text{Prob}[d_{it}^n = 1] = a^n \cdot r_{it}^n \cdot K_{it}$	binomial
$\boldsymbol{a^m}$	2.5	parameter
$\boldsymbol{a^n}$	0.025	parameter
$\boldsymbol{\Omega_t(\gamma)}$		cost distribution
$\boldsymbol{\Omega_t^+(\gamma)}$	$logN(L_t, 0.1177)$	cost opportunity distribution
$\boldsymbol{g_{\min}; g_{\max}}$	[0.1;0.2]	support of Ω in t=0
$\boldsymbol{\gamma_{it}^m}$		result imitation draw
$\boldsymbol{\gamma_{it}^n}$		result innovation draw
Entry		
$\boldsymbol{B_t^m}$	$a^m \cdot R^m$	mean imitative entries
$\boldsymbol{B_t^n}$	$a^n \cdot R^n$	mean innovative entries
$\boldsymbol{R^m}$	0.2	parameter

$\boldsymbol{R^n}$	2	parameter
$\boldsymbol{\gamma_e}$		result draw
$\boldsymbol{K_e}$	$K \sim N(24, 7.5)$	truncated at $K^{\min}$
$\boldsymbol{r_e^m}$	$\bar{r}_t^m$	
$\boldsymbol{r_e^n}$	$\bar{r}_t^n$	
$\boldsymbol{r^e}$	$r_{i,0}^m + r_{i,0}^n$	entry barrier
$\boldsymbol{u_{it}^e}$	N(0, σ_e)>0, $\sigma_e = 0.5$	disturbance
Other		
$\boldsymbol{\tau}$	3	constant policy
$\boldsymbol{\theta}$	0.75	adjustment parameter (X)
$\boldsymbol{\beta}$	0.167	adjustment parameter (R&D)
$\boldsymbol{h_r}$	0.5	probability of policy change
$\boldsymbol{u_{it}^m}$	N(0, σ^m)>0, $\sigma^m = 0.0004$	disturbance
$\boldsymbol{u_{it}^n}$	N(0, σ^n)>0, $\sigma^n = 0.002$	disturbance
$\boldsymbol{\iota}$	10	patent protection

Appendix C

Programme Code

Input of Data

```
load vorperiodendaten

firm_start=length(pi_it(find(pi_it>0 | pi_it<0)));

K_it=K_it(find(pi_it>0 | pi_it<0));
E_it=E_it(find(pi_it>0 | pi_it<0));
E_t=sum(E_it);
P_it=P_it(find(pi_it>0 | pi_it<0));
firm_start=length(K_it);
pi_it=pi_it(find(pi_it>0 | pi_it<0));
Q_it=Q_it(find(pi_it>0 | pi_it<0));
gamma_it=gamma_it(find(pi_it>0 | pi_it<0));
X_it=X_it(find(pi_it>0 | pi_it<0));
I_it=I_it(find(pi_it>0 | pi_it<0));
rm_it=rm_it(find(pi_it>0 | pi_it<0));
rn_it=rn_it(find(pi_it>0 | pi_it<0));
```

Dynamic Model

```
seedzahl=input('seedzahl= ');
Time=99;

randn('seed',blubb)
rand('seed',blubb)
```

Construction of Matrices of Results

Determination of matrix dimension

```
firm_max=150;
active=firm_start;
platz=firm_max-firm_start;
```

Using Data of $t = 0$ and adjusting matrix dimension

```
E_it=[E_it NaN*ones(1,platz)];
EE=[E_it];

P_it=[P_it NaN*ones(1,platz)];
PP=[P_it];

CAL_Z=[];
CAL_Z=[1:firm_start NaN*ones(1,platz)];

pi_it=[pi_it NaN*ones(1,platz)];
PI=[pi_it];

Q_it=[Q_it NaN*ones(1,platz)];
QQ=[Q_it];

qq=[];
q_it=Q_it;
qq=[q_it];

K_it=[K_it NaN*ones(1,platz)];
KK=[K_it];

gamma_it=[gamma_it NaN*ones(1,platz)];
GAMMA=[gamma_it];

DM=[];
DN=[];

Gammam=[];
Gamman=[];

X_it=[X_it NaN*ones(1,platz)];
X=[X_it];

rm_it=[rm_it NaN*ones(1,platz)];
RM=[rm_it];

rn_it=[rn_it NaN*ones(1,platz)];
RN=[rn_it];

I_it=[I_it NaN*ones(1,platz)];
I=[I_it];

IF=[];
ID=[];
```

```
ZETA=[zeta_t];

PHI=[phi];

EXIT1=[];
EXIT2=[];

ENTRY_M=[];
ENTRY_N=[];

POTENTRY_M=[];
POTENTRY_N=[];

Patent=[];

L_0=0.16;
g_L=0.99;
```

for t=1:Time

Latent Productivity

```
L_t=L_0*g_L^(t-1);
```

Consumers

```
kappa0=lambda0/zeta_t;
kappa1=lambda1/zeta_t;
```

Computation of Prices

Determination of the reservation price (phi)

```
b=1.5*(gmax+rho+delta+rm+rn);
phi0_=[min(min(gamma_it(gamma_it>0)),gmin):.001:10 10:0.01:100];
sP_it=sort(P_it(find(P_it>0)));
x_0=min(sP_it)-0.001;
aa=length(sP_it)/(sum(log(sP_it/x_0)));
F_X=1-(x_0./phi0_).^aa;
F0_=b+(lambda0-lambda1)*F_X./(zeta_t+lambda1*F_X);
phi0_1=round(10*phi0_);
F0_1=round(10*F0_);
phi=mean(phi0_(find(phi0_1==F0_1)));
```

Determination of the price-output relation

```
step=0.0001;
P_=[min(gamma_it(gamma_it>0))+2*(rho+delta):step:phi];
l_P=(E_t/active)*(1+kappa1)./((1+kappa1*2*(normcdf(P_,0,1)-0.5)).^2);
```

Choosing output

```
minl_P=min(round(l_P*10));
maxl_P=max(round(l_P*10));
```

Matching of the price to the output of a firm

```
P_it=[];
for i=1:1:firm_max
if CAL_Z(t,i)>0
if round(Q_it(i)*10)>=minl_P
if round(Q_it(i)*10)<=maxl_P
P_it=[P_it mean(P_([find(round(l_P*10)==round(Q_it(i)*10)) ...
find(round(l_P*10)==(round(Q_it(i)*10))-1) ...
find(round(l_P*10)==(round(Q_it(i)*10))+1)]))];
elseif round(Q_it(i)*10)>maxl_P
P_it=[P_it gamma_it(i)+rho+delta+rm_it(i)+rn_it(i)];
end
elseif round(Q_it(i)*10)<minl_P
P_it=[P_it phi];
end
elseif CAL_Z(t,i)==0
P_it=[P_it 0];
elseif isnan(CAL_Z(t,i))==1
P_it=[P_it NaN];
end
end
```

Consumer Movements

Change of current supplier (lambda1)

```
if t>=2
```

Customers leaving their old firm (without new firms)

```
E_it0=E_it;
E_it=[];
ADD=[0];
for i=1:firm_max
if CAL_Z(t,i)>0
```

```
if isnan(CAL_Z(t-1,i))==0
CA=CAL_Z(t,:);
CAL_Z_=CA(find(CAL_Z(t,:)>0));
w=0;
for j=1:round(lambda1*E_it0(i))
uu=round(unifrnd(0.5,length(CAL_Z_)+0.49,1,1));
if P_it(i)>P_it(CAL_Z_(uu))
w=w+1;
ADD=[ADD CAL_Z_(uu)];
else
w=w;
end
end
E_it=[E_it E_it0(i)-w];
elseif isnan(CAL_Z(t-1,i))==1
E_it=[E_it E_it0(i)];
end % of if isnan(CAL_Z(t-1,i))==0
elseif CAL_Z(t,i)==0
E_it=[E_it 0];
elseif isnan(CAL_Z(t,i))==1
E_it=[E_it NaN];
end
end % of for i=1:firm_max
```

Consumers who have found a cheaper supplier (including new firms)

```
E_it0=E_it;
E_it=[];
for h=1:firm_max
E_it=[E_it E_it0(h)+sum(ADD==h)];
end


end % of if t>=2
```

Consumers moving from U to E (lambda0) (without new firms)

```
if t>=2
```

```
E_it0=E_it;
E_it=[];
for i=1:firm_max
if CAL_Z(t,i)>0
if isnan(CAL_Z(t-1,i))==0
if N>E_t
E_it=[E_it E_it0(i)+round(lambda0*(N-E_t)/active)];
elseif N<=E_t
```

```
E_it=[E_it E_it0(i)];
end
elseif isnan(CAL_Z(t-1,i))==1
E_it=[E_it E_it0(i)];
end % of isnan(CAL_Z(t-1,i))==0
elseif CAL_Z(t,i)==0
E_it=[E_it 0];
elseif isnan(CAL_Z(t,i))==1
E_it=[E_it NaN];
end
end end % of if t>=2
```

Quantity sold by a firm

```
q_it=min(E_it,Q_it);
```

Profit & Performance

Profit

```
pi_it=[];
for i=1:firm_max
if CAL_Z(t,i)>0
pi_it=[pi_it P_it(i)*q_it(i)-gamma_it(i)*Q_it(i)- ...
(rm_it(i)+rn_it(i))*K_it(i)-(rho+delta)*K_it(i)];
elseif CAL_Z(t,i)==0
pi_it=[pi_it 0];
elseif isnan(CAL_Z(t,i))==1
pi_it=[pi_it NaN];
end
end
```

Performance

```
X_it=[];
theta=0.75;
for i=1:firm_max
if CAL_Z(t,i)>0
X_it=[X_it theta*X(t,i)+(1-theta)*pi_it(i)];
elseif CAL_Z(t,i)==0
X_it=[X_it 0];
elseif isnan(CAL_Z(t,i))==1
X_it=[X_it NaN];
end
end
```

Exit condition 1

Aspiration level

```
X_imin=[];
for i=1:firm_max
if CAL_Z(t,i)>0
X_imin=[X_imin -(rho+delta)*K_it(i)];
elseif CAL_Z(t,i)==0
X_imin=[X_imin 0];
elseif isnan(CAL_Z(t,i))==1
X_imin=[X_imin NaN];
end
end
```

Remaining firms

```
CAL_Z1=CAL_Z(t,:);
exit1=length((find(CAL_Z1(X_it<X_imin))));
CAL_Z1([find(X_it<X_imin)])=0;
active1=(length(CAL_Z1)-sum(CAL_Z1==0)-sum(isnan(CAL_Z1)));
```

Policy adjustment

```
barpi_t=nanmean(pi_it(find(CAL_Z1>0)));
barrm_t=nanmean(rm_it(find(CAL_Z1>0)));
barrn_t=nanmean(rn_it(find(CAL_Z1>0)));


beta=0.167;
hr=0.5;
tau_r=3;
if t>=tau_r+1
```

Adjustment of imitation efforts

```
rm_it0=rm_it;
rm_it=[];
for i=1:firm_max
if CAL_Z1(i)>0
if mean(RM(t-tau_r:t,i))==RM(t,i)
if X_it(i)>=barpi_t
rm_it=[rm_it rm_it0(i)];
elseif X_it(i)<barpi_t
probm=unifrnd(0,1,1,1);
if probm<=hr
um_it=abs(normrnd(0,0.0004,1,1));
```

```
rm_it=[rm_it (1-beta)*rm_it0(i)+beta*barrm_t+um_it];
elseif probm>hr
rm_it=[rm_it rm_it0(i)];
end
end
elseif mean(RM(t-tau_r:t,i)) =RM(t,i)
rm_it=[rm_it rm_it0(i)];
end
elseif CAL_Z1(i)==0
rm_it=[rm_it 0];
elseif isnan(CAL_Z1(i))==1
rm_it=[rm_it NaN];
end
end
```

Adjustment of innovation efforts

```
rn_it0=rn_it;
rn_it=[];

for i=1:firm_max
if CAL_Z1(i)>0
if mean(RN(t-tau_r:t,i))==RN(t,i)
if X_it(i)>=barpi_t
rn_it=[rn_it rn_it0(i)];
elseif X_it(i)<barpi_t
probn=unifrnd(0,1,1,1);
if probn<=hr
un_it=abs(normrnd(0,0.0004,1,1));
rn_it=[rn_it (1-beta)*rn_it0(i)+beta*barrn_t+un_it];
elseif probn>hr
rn_it=[rn_it rn_it0(i)];
end
end
elseif mean(RN(t-tau_r:t,i)) =RN(t,i)
rn_it=[rn_it rn_it0(i)];
end
elseif CAL_Z1(i)==0
rn_it=[rn_it 0];
elseif isnan(CAL_Z1(i))==1
rn_it=[rn_it NaN];
end
end

end % end of t>=tau_r+1
```

Investment

Financeable investment

```
IF_it=[];
for k=1:firm_max
if CAL_Z1(k)>0
if pi_it(k)>0
IF_it=[IF_it delta+3*(pi_it(k)/K_it(k))];
elseif pi_it(k)<=0
IF_it=[IF_it delta+(pi_it(k)/K_it(k))];
end
elseif CAL_Z1(k)==0
IF_it=[IF_it 0];
elseif isnan(CAL_Z1(k))==1
IF_it=[IF_it NaN];
end
end
```

Desired investment

```
ID_it=[];
for i=1:firm_max
if CAL_Z1(i)>0
if Q_it(i)==0
Q_it=0.5*K_it;
end
ID_it=[ID_it delta+(1/K_it(i))*round(lambda0*(N-E_t)/active)+ ...
(q_it(i)/Q_it(i))*(1/Q_it(i))];
elseif CAL_Z1(i)==0
ID_it=[ID_it 0];
elseif isnan(CAL_Z1(i))==1
ID_it=[ID_it NaN];
end
end
```

Investment

```
I_it=[];
K_it0=K_it;
K_it=[];
for i=1:firm_max
if CAL_Z1(i)>0
I_it=[I_it max(0,min(IF_it(i),ID_it(i)))];
K_it=[K_it I_it(i)*K_it0(i)+(1-delta)*K_it0(i)];
elseif CAL_Z1(i)==0
I_it=[I_it 0];
```

```
K_it=[K_it 0];
elseif isnan(CAL_Z1(i))==1
I_it=[I_it NaN];
K_it=[K_it NaN];
end
end
```

Exit condition 2

Aspiration level

```
Kmin=15;
```

Remaining firms

```
CAL_Z2=CAL_Z1;
exit2=length((find(CAL_Z2(K_it<Kmin & K_it>0))));
CAL_Z2([find(K_it<Kmin)])=0;
active2=(length(CAL_Z2)-sum(CAL_Z2==0)-sum(isnan(CAL_Z2)));
```

Number of exiting firms in the current period

```
zeta=(active-active2)/active;
if zeta==0
zeta_t=min(ZETA);
else
zeta_t=zeta;
end
ZETA=[ZETA zeta_t];
```

Output of the next period

```
Q_it=[];
for i=1:firm_max
if CAL_Z2(i)>0
Q_it=[Q_it .5*K_it(i)];
elseif CAL_Z2(i)==0
Q_it=[Q_it 0];
elseif isnan(CAL_Z2(i))==1
Q_it=[Q_it NaN];
end
end
```

Imitation and innovation

```
am=2.5;
an=0.025;
```

Result of the imitative draw

```
jota=10; % patent protection for jota periods
```

```
GAMMA0=[zeros(jota,firm_max);GAMMA];
DM0=[zeros(jota,firm_max);DM];
DN0=[zeros(jota,firm_max);DN];
patent=[];
for j=1:firm_ max
if CAL_Z2(j)>0
if mean(GAMMA0(t:t+jota-1,j))==gamma_it(j)
patent=[patent 1];
elseif mean(GAMMA0(t:t+jota-1,j)) =gamma_it(j)
if sum(DN0(t:t+jota-1,j))>0
patent=[patent 0];
else patent=[patent 1];
end
end
else
patent=[patent 0];
end
end
```

```
KK0=KK(t,:);
rK_it=round(KK0(find(patent>0)));
g_it=gamma_it(find(patent>0));


wgamma_it=[];
for j=1:length(rK_it)
wgamma_it=[wgamma_it g_it(j)*ones(1,rK_it(j))];
end
zahlm=round(unifrnd(0.5,sum(rK_it)+0.49,1,firm_max));
gamma_imi=[];
for j=1:firm_max
gamma_imi=[gamma_imi wgamma_it(zahlm(j))];
end
```

Determining if the firm has an imitative draw

```
dm=[];
for i=1:firm_max
if CAL_Z2(i)>0
```

```
zzahlm=unifrnd(0,1,1,1);
if zzahlm<=am*RM(t,i)*KK(t,i)
dm=[dm 1];
elseif zzahlm>am*RM(t,i)*KK(t,i)
dm=[dm 0];
end
elseif CAL_Z2(i)==0
dm=[dm 0];
elseif isnan(CAL_Z2(i))==1
dm=[dm NaN];
end
end

gammam_i=dm.*gamma_imi;
```

Determining if the firm has an innovative draw

```
dn=[];
for i=1:firm_max
if CAL_Z2(i)>0
zzahln=unifrnd(0,1,1,1);
if zzahln<=an*RN(t,i)*KK(t,i)
dn=[dn 1];
elseif zzahln>an*RN(t,i)*KK(t,i)
dn=[dn 0];
end
elseif CAL_Z2(i)==0
dn=[dn 0];
elseif isnan(CAL_Z2(i))==1
dn=[dn NaN];
end
end
```

Result of the innovative draw

```
zahlz=abs(log(lognrnd(L_t,0.1177,1,100*firm_max)));
```

Restricting gamma from below

```
gamman_i0=zahlz(find(zahlz>0.005 & zahlz<=max(gamma_it)));
if isempty(gamman_i0)==1
gamman_i0=.005;
end

zahlzz=round(unifrnd(0.5,length(gamman_i0)+0.4999,1,firm_max));
gamman_i=dn.*gamman_i0(zahlzz);
```

Actual technology of the next period

```
gamma_it=[];
for i=1:firm_max
if CAL_Z2(i)>0
if gammam_i(i)>0
if gamman_i(i)>0
gamma_it=[gamma_it min([GAMMA(t,i);gammam_i(i);gamman_i(i)])];
elseif gamman_i(i)==0
gamma_it=[gamma_it min([GAMMA(t,i);gammam_i(i)])];
end
elseif gammam_i(i)==0
if gamman_i(i)>0
gamma_it=[gamma_it min([GAMMA(t,i);gamman_i(i)])];
elseif gamman_i(i)==0
gamma_it=[gamma_it GAMMA(t,i)];
end
end
elseif CAL_Z2(i)==0
gamma_it=[gamma_it 0];
elseif isnan(CAL_Z2(i))==1
gamma_it=[gamma_it NaN];
end
end
```

Entry

```
barrm_t=nanmean(rm_it(find(CAL_Z2>0)));
barrn_t=nanmean(rn_it(find(CAL_Z2>0)));
```

Poisson distribution

```
mm=1:1:10; % maximum number of entering firms
Rm=0.2;
Bm=am*Rm;
f_mm=(exp(1).^(-Bm).*Bm.^mm)./cumprod(mm);
```

```
nn=1:1:10; % maximum number of entering firms
Rn=2;
Bn=an*Rn;
f_nn=(exp(1).^(-Bn).*Bn.^nn)./cumprod(nn);
```

Determination of the number of imitative entrants (ZM_)

```
re=rm+rn; % entry barrier rate
```

```
uni=unifrnd(0,1,1,1);
if uni<1-sum(f_mm); ZM=0;
elseif uni>1-sum(f_mm) & uni<1-sum(f_mm)+f_mm(1); ZM=1;
elseif uni>1-sum(f_mm)+f_mm(1) & uni<1-sum(f_mm)+sum(f_mm(1:2)); ZM=2;
elseif uni>1-sum(f_mm)+sum(f_mm(1:2)) & uni<1-sum(f_mm)+sum(f_mm(1:3)); ZM=3;
elseif uni>1-sum(f_mm)+sum(f_mm(1:3)) & uni<1-sum(f_mm)+sum(f_mm(1:4)); ZM=4;
elseif uni>1-sum(f_mm)+sum(f_mm(1:4)) & uni<1-sum(f_mm)+sum(f_mm(1:5)); ZM=5;
elseif uni>1-sum(f_mm)+sum(f_mm(1:5)) & uni<1-sum(f_mm)+sum(f_mm(1:6)); ZM=6;
elseif uni>1-sum(f_mm)+sum(f_mm(1:6)) & uni<1-sum(f_mm)+sum(f_mm(1:7)); ZM=7;
elseif uni>1-sum(f_mm)+sum(f_mm(1:7)) & uni<1-sum(f_mm)+sum(f_mm(1:8)); ZM=8;
elseif uni>1-sum(f_mm)+sum(f_mm(1:8)) & uni<1-sum(f_mm)+sum(f_mm(1:9)); ZM=9;
end

if ZM>=1
K_zm=normrnd(VK,7.5,1,ZM);
Q_zm=0.5*K_zm;

zahlm=round(unifrnd(0.5,sum(rK_it)+0.49,1,ZM));
gamma_zm=[];
for j=1:ZM
gamma_zm=[gamma_zm wgamma_it(zahlm(j))];
end

P_zm=[];
for i=1:ZM
if Q_zm(i)>=minl_P
P_zm=[P_zm mean(P_(find(round(l_P*10)==round(Q_zm(i)*10))))];
elseif Q_zm(i)<minl_P
P_zm=[P_zm phi];
end
end
```

Entry decision

```
c_zm=gamma_zm+rho+delta;
ue=abs(normrnd(0,0.5,1,ZM));

ZM_=find((P_zm-c_zm).*Q_zm>re+ue); % imitative entrants

elseif ZM==0
ZM_=[];
K_zm=[];
Q_zm=[];
P_zm=[];
gamma_zm=[];
end % of if zm>=1
```

Determination of the number of innovative entrants (ZN_)

```
uni=unifrnd(0,1,1,1);
if uni<1-sum(f_nn); ZN=0;
elseif uni>1-sum(f_nn) & uni<1-sum(f_nn)+f_nn(1); ZN=1;
elseif uni>1-sum(f_nn)+f_nn(1) & uni<1-sum(f_nn)+sum(f_nn(1:2)); ZN=2;
elseif uni>1-sum(f_nn)+sum(f_nn(1:2)) & uni<1-sum(f_nn)+sum(f_nn(1:3)); ZN=3;
elseif uni>1-sum(f_nn)+sum(f_nn(1:3)) & uni<1-sum(f_nn)+sum(f_nn(1:4)); ZN=4;
elseif uni>1-sum(f_nn)+sum(f_nn(1:4)) & uni<1-sum(f_nn)+sum(f_nn(1:5)); ZN=5;
elseif uni>1-sum(f_nn)+sum(f_nn(1:5)) & uni<1-sum(f_nn)+sum(f_nn(1:6)); ZN=6;
elseif uni>1-sum(f_nn)+sum(f_nn(1:6)) & uni<1-sum(f_nn)+sum(f_nn(1:7)); ZN=7;
elseif uni>1-sum(f_nn)+sum(f_nn(1:7)) & uni<1-sum(f_nn)+sum(f_nn(1:8)); ZN=8;
elseif uni>1-sum(f_nn)+sum(f_nn(1:8)) & uni<1-sum(f_nn)+sum(f_nn(1:9)); ZN=9;
end

if ZN>=1
K_zn=normrnd(VK,7.5,1,ZN);
Q_zn=0.5*K_zn;
zahln=abs(log(lognrnd(L_t,0.1177,1,100*firm_max)));
gamma_zn0=zahln(find(zahln>0.005 & zahln<=max(gamma_it)));
if isempty(gamma_zn0)==1
gamma_zn0=[.005*ones(1,ZN)];
end

gamma_zn=gamma_zn0(1:ZN);

P_zn=[];
for i=1:ZN
if Q_zn(i)>=minl_P
P_zn=[P_zn mean(P_(find(round(l_P*10)==round(Q_zn(i)*10))))];
elseif Q_zn(i)<minl_P
P_zn=[P_zn phi];
end
end
```

Entry decision

```
c_zn=gamma_zn+rho+delta;
ue=abs(normrnd(0,0.5,1,ZN));
ZN_=find((P_zn-c_zn).*Q_zn>re+ue); % innovative entrants

elseif ZN==0
ZN_=[];
K_zn=[];
Q_zn=[];
P_zn=[];
gamma_zn=[];

end % of if zn>=1
```

Update of the number of active firms

```
lcalz2=length(CAL_Z2)-sum(isnan(CAL_Z2));
CAL_Z30=[CAL_Z2(find(CAL_Z2>=0)) lcalz2+ ...
1:1:(lcalz2+length(ZM_)+length(ZN_))];
CAL_Z3=[CAL_Z30 NaN*ones(1,(firm_max-length(CAL_Z30)))];

active=(length(CAL_Z3)-sum(CAL_Z3==0)-sum(isnan(CAL_Z3)));
```

Active customers after both exits

```
E_t=nansum(E_it(find(CAL_Z2>0)));
```

Customers for the new firms (next period)

```
E_zm=[];
if length(ZM_)==0
E_zm=[];
elseif length(ZM_)>0
E_zm=min(round(lambda0*(N-E_t)/active),Q_zm(1:length(ZM_)));
end

E_zn=[];
if length(ZN_)==0
E_zn=[];
elseif length(ZN_)>0
E_zn=min(round(lambda0*(N-E_t)/active),Q_zn(1:length(ZN_)));
end
```

Update of Vectors for Entrants

```
K_it=[K_it(find(CAL_Z2>=0)) K_zm(ZM_) K_zn(ZN_) ...
NaN*ones(1,(firm_max-length(K_it(find(CAL_Z2>=0))) ...
-length(K_zm(ZM_))-length(K_zn(ZN_))))];
Q_it=[Q_it(find(CAL_Z2>=0)) Q_zm(ZM_) Q_zn(ZN_) ...
NaN*ones(1,(firm_max-length(Q_it(find(CAL_Z2>=0))) ...
-length(Q_zm(ZM_))-length(Q_zn(ZN_))))];
E_it=[E_it(find(CAL_Z3>=0)) ...
NaN*ones(1,(firm_max-length(E_it(find(CAL_Z2>=0))) ...
-length(E_zm)-length(E_zn)))];
rm_it=[rm_it(find(CAL_Z2>=0)) barrm_t*ones(1,(length(ZM_) ...
+length(ZN_))) NaN*ones(1,(firm_max-length(rm_it(find(CAL_Z2>=0))) ...
-length(ZM_)-length(ZN_)))];
rn_it=[rn_it(find(CAL_Z2>=0)) barrn_t*ones(1,(length(ZM_) ...
+length(ZN_))) NaN*ones(1,(firm_max-length(rn_it(find(CAL_Z2>=0))) ...
-length(ZM_)-length(ZN_)))];
gamma_it=[gamma_it(find(CAL_Z2>=0)) ...
```

```
gamma_zm(ZM_) gamma_zn(ZN_) ...
NaN*ones(1,(firm_max-length(gamma_it(find(CAL_Z2>=0))) ...
-length(gamma_zm(ZM_))-length(gamma_zn(ZN_))))];
P_it=[P_it(find(CAL_Z2>=0)) P_zm(ZM_) P_zn(ZN_) ...
NaN*ones(1,(firm_max-length(P_it(find(CAL_Z2>=0))) ...
-length(P_zm(ZM_))-length(P_zn(ZN_))))];
X_it=[X_it(find(CAL_Z2>=0)) 0.01*ones(1,(length(ZM_)+length(ZN_))) ...
NaN*ones(1,(firm_max-length(X_it(find(CAL_Z2>=0))) ...
-length(ZM_)-length(ZN_)))];
```

Collection of results

```
KK=[KK;K_it];
QQ=[QQ;Q_it];
qq=[qq;q_it];
EE=[EE;round(E_it)];
PHI=[PHI phi];
PP=[PP;P_it];
PI=[PI;pi_it];
X=[X;X_it];
I=[I;I_it];
IF=[IF;IF_it];
ID=[ID;ID_it];
DM=[DM;dm];
DN=[DN;dn];
GAMMA=[GAMMA;gamma_it];
Gammam=[Gammam gammam_i];
Gamman=[Gamman gamman_i];
RM=[RM;rm_it];
RN=[RN;rn_it];
EXIT1=[EXIT1 exit1];
EXIT2=[EXIT2 exit2];
POTENTRY_M=[POTENTRY_M ZM];
POTENTRY_N=[POTENTRY_N ZN];
ENTRY_M=[ENTRY_M length(ZM_)];
ENTRY_N=[ENTRY_N length(ZN_)];
Patent=[Patent;patent];
CAL_Z=[CAL_Z;CAL_Z3];
```

end

Appendix D

Supplements

Table D.1: Number of Variables Included in the Price Densities

Case	$t = 20$	$t = 60$	$t = 100$
Case I	4487	4971	7019
Case II	3166	3949	5628
Case III	2182	3527	4857
Case IV	3776	4664	6785

Table D.2: Profitability: Price-cost Margin[abc]

	Phase	Phase I		Phase II		Phase III	
Case	Firms	PCM	RRA	PCM	RRA	PCM	RRA
Case I	Small	5.1554	1.3137	4.4983	2.0945	4.6808	2.6114
	Medium	4.6839	1.5720	4.9756	3.5184	5.9658	4.8299
	Large	2.4402	1.5731	2.2250	2.4835	3.0927	3.3079
Case II	Small	6.3893	1.4839	6.9872	2.4040	6.6720	2.7699
	Medium	5.4499	2.0632	5.7053	4.0623	7.2855	5.6153
	Large	1.4962	1.4302	1.7390	2.3049	3.1701	3.7045
Case III	Small	7.4895	1.7267	8.4920	2.7296	8.9063	3.4331
	Medium	5.2734	2.2584	5.4156	4.0591	7.6422	6.0070
	Large	1.1117	1.2729	1.6164	2.3074	3.3326	3.9800
Case IV	Small	8.0477	1.5901	6.6164	2.5330	6.3516	3.1469
	Medium	7.1245	1.7686	6.4263	4.0304	6.9507	5.5846
	Large	3.4078	2.1187	2.9210	2.9083	3.5510	3.6612

[a]For simplicity, to distinguish between small, medium and large firms, the total number of firms has been equally divided into three parts.
[b]The numbers in the table are the arithmetic means of the corresponding variables.
[c]PCM: price-cost margin; RRA: required rental on assets.

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