

Innovation and Proximity

Aspects of Firm Strategy and Public Policy in an
Agent-Based Simulation Model

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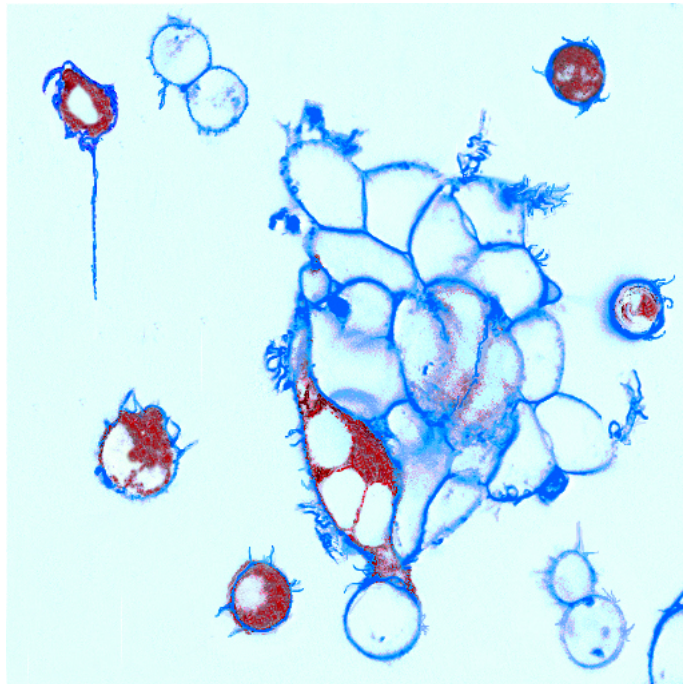
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Innovation and proximity at the cellular level.

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Chapter 1

Introduction

This book picks the influence of proximity on the innovative behavior of firms out as a central theme. We follow Whetten (1989), who introduces three questions which should help to disclose the essential elements of a theoretical contribution: Why? What? How? We will give short answers to get an idea of the purpose and scope of this work.

Why?

This question asks about the relevance and logic underlying the contribution. Why should other researchers be interested in this topic and what view of the economy does the author take?

In our understanding the main driver of competition between firms is knowledge. Firms differ in their knowledge about production technologies and consumer needs. Further, knowledge is seen as the major input factor for the introduction of organizational or production improvements as well as for the design of new products. The first idea is related to process innovations and the second to product innovations. Different forms of proximity have an impact on the build-up and exchange of knowledge. Therefore, the appreciation of the role of knowledge - and economically useful knowledge¹ especially - becomes crucial when talking about innovative competition between firms.

Knowledge is of major importance not only for the single firm but the whole economy. Some authors even state that we live in a knowledge economy (Nonaka and Takeuchi, 1995; Cooke and Leydesdorf, 2006). Indeed, there appears to be a deep connection between research and development activities (R&D) and the economic performance of a country as technology accounts for at least 50% of the economic growth (Solow, 1956; Lambooy, 2005).

The European Union (EU) acknowledged this argument and put priority to knowledge and economic growth in the Lisbon Agenda constituted in the year 2000

¹The notion of economically useful knowledge is mentioned in Lundvall (1992).

by the European Council. The goal of this agenda is to make the European Union the 'most competitive and dynamic knowledge-based economy in the world' which at the same time accredits the leading role of the USA . The political measures within the scope of the Lisbon Agenda were initiated because it is believed that economic growth enables the achievement of political, economic, social, and environmental objectives of the enlarged Union, besides, a policy aiming at cohesion tends to foster economic growth, and sustained growth is necessary to ensure cohesion of the EU (Sapir, 2004).² Hence, we are convinced of the significant role of knowledge for the economic performance at a firm, national and supra-national level. Despite the fact that the relevance of knowledge is widely accepted we discover a gap in the current literature that is related to the mechanisms and economic consequences of the dependency on knowledge. This brings us to the next point.

What?

The second question highlights the selection of factors which explain the phenomena of interest. Here the right factors have to be included and the theoretical model has to abstract from other factors which do not lead to many additional insights.

First, we admit that we concentrate on innovative competition between firms which are at the same time competitors on goods markets. We neglect possible positive or negative effects of the spread of knowledge among economic actors from other industries. Our main interest lies in the trade-off for firms which emerges due to the acquisition of external knowledge versus the potential loss of economically critical knowledge. The first aspect is typically considered to have a positive influence on the economic situation of the firm as additional knowledge helps to develop and adopt innovations. The second aspect may impose negative consequences on the economic profits as firms want to differ from competitors in order to earn economic rents.

Second, in this work we abstract from all locational factors but learning through knowledge spillovers. This endeavor is interesting and can be justified because knowledge spillovers can at the same time be convincing for one firm and deterring for another firm preventing its becoming an active member of the knowledge exchange process.

Third, we concentrate on two forms of proximity as main influencing factors for learning: Geographical and technological proximity. In order to shed light on the impact of the two types of proximity on knowledge spillovers we give two simple examples. We argue that geographical proximity favors the exchange of ideas and, hence, the flow of knowledge. In university, there are many opportunities for personal contact and researchers also seek direct communication at conferences and meetings,

²See Chapter 8 for a critique on this proposition.

which can be interpreted as geographical proximity, too. This is done because it is often easier and faster to explain scientific methods and results face-to-face than using other sources like research articles. Further, one can imagine a situation where a researcher is very active in his community and another researcher who fully focuses on one topic and does not seek the regular exchange with other scholars from his discipline. Being more involved in the actual discussions helps to develop or extend new arguments which increase existing concepts in many small steps. But one would expect that a greater scientific breakthrough challenging the usual thinking is more likely to be caused by a researcher in isolation because he is not so much involved in the group. We see that geographical proximity might have important impact on learning and the build-up of knowledge.

Technological proximity is related to specialization. Let us assume a student in economics who has to decide upon three fields: Microeconomics, Macroeconomics and Econometrics. He may study those subjects in equal shares to achieve a more balanced knowledge. On the other hand, he might decide to pick a major and concentrate on e.g. Microeconomics or - even more specialized - on Industrial Organization as a part of Microeconomics. The labor market will show which would have been the best strategy. The wage and economic situation of the student depends on the chosen majors of his fellow students as well as on the needs of firms and public institutions as potential employers. The same holds for firms in economic competition when they decide upon their innovation strategy.

We believe that the influence of geographical and technological proximity on learning and its consequences for innovative competition are so far not fully understood. Therefore, we will attempt to show how this topic can be handled in an economic model and what kind of results can be obtained.

How?

After the identification of the topic and main factors an author should reveal the relationship between the chosen factors. Here this is done with the help of formalization in a simulation model which is analyzed in computational experiments.

We decided to use the method of agent-based simulations to represent our ideas of innovation and proximity in a formal model. The relationship of the several factors and the assumptions about the (economic) behavior of the agents are described by formulas which are implemented in a computational program. The repetition of several simulation runs with different parameter settings allows the testing of our hypothesis, while the computational experiments act as a tool for theory building. We choose agent-based simulation because it allows to capture dynamic interactions and a useful representation of knowledge, uncertainty, and heterogeneity. Those aspects are argued to be essential for handling innovation, technological change, and

learning in a theoretical model. The main advantages of our model are the representation of an endogenous technological development in the form of process and product innovations, the quantification of learning effects depending on geographical and technological proximity, and the quantification of the economic value of knowledge. These features help to disentangle relevant mechanisms for the impact of proximity on the innovative competition between firms and the emergent outcome in the form of technological development and clustering of firms in an agglomeration.

Another methodological distinctive feature is given due to the fact that we take two different perspectives in the analysis: First, we try to indicate innovation strategies which help firms to earn more profits. Second, we investigate the outcome from the viewpoint of economic policy. While doing so we reveal potential policy measures and confront them with the industry model to evaluate their effectiveness. For both - firms and policy - the topic of innovation is important and we give an example how issues from both fields can be assessed with the same methodology.

In the following we provide a list of research questions which are investigated in this book. Although the list does not contain all of the results presented in the corresponding chapters, it might be useful to give an overview and to subsume the findings in a nutshell. Furthermore, we had these questions in mind while developing and modifying the theoretical model which might have had an influence on the model as it is now. The answers to our research questions are presented in Chapter 8 as part of the conclusions.

Research Questions:

1. Should firms seek for geographical proximity to competitors? Do positive effects of external learning outweigh negative effects due to the loss of knowledge lead?
2. Does the importance of geographical proximity change during time?
3. What kind of firms enter agglomerations: Technologically advanced or technologically weak firms?
4. Are firms that specialize in their innovation efforts more economically successful than firms that diversify?
5. What kind of agglomerations emerge: Technologically specialized or diversified agglomerations?
6. What technological environment supports the flow of knowledge spillovers?
7. Can political interventions aiming to foster the technological development be justified?

8. What are possible measures of regional innovation policy in this context, and do they work?

In order to address these research questions the book is divided into four parts. The first Part I has an introductory character and reviews the relevant literature on innovation and proximity. We start in Chapter 2 with a discussion of the relationship between knowledge, innovation, competition, and economic growth. Here the concept of knowledge spillover and its dependency on proximity is elaborated. We focus on geographical and technological proximity and present our interpretation of these notions. The main findings in the literature propose that geographical proximity enhances learning and that the relation of learning and technological proximity takes a non-linear form. Chapter 3 summarizes previous attempts to incorporate aspects of innovation and proximity in formal economic models. Although there exist promising efforts to build analytical models, we argue that the usage of simulation models in the context of innovation and proximity can be justified. We list and debate various simulation models which deal with geographical and/or technological proximity, but there appears to be no industry model available which would combine both types of proximity and relate them to innovative competition.

Part II introduces our proposal to fill this research gap. In Chapter 4 we construct an agent-based simulation model of an innovative industry where heterogeneous firms decide upon market entry and exit, quantities, geographical location, and investments in R&D which is connected to technological and market positioning. Learning in the form of knowledge spillovers increases with geographical proximity and when the absorptive capacity of the firm approaches the technological gap between the interacting partners. Profits are realized due to the interaction on product markets with consumers characterized by heterogeneous preferences. In Chapter 5, the parametrization of the simulation model is discussed in the context of model verification. Further, we perform model validation and compare simulation outcome with data and stylized facts found in the empirical literature. Findings suggest that our model appears to replicate major industry characteristics.

Part III applies our model to several problems which are related to our research questions. Chapter 6 is devoted to an analysis from the viewpoint of a firm. We begin by looking at our understanding of specialization. Then, we point out the effect of different firm strategy parameters on firm profits with the help of a regression analysis. The next section deals with the incentive of firms to seek geographical proximity. Despite the fact that in early times many firms choose a location in the agglomeration, the number of cluster firms decreases over time. We provide two reasons for this result: An adverse selection and a lock-in effect where both work against the benefits of a location in close geographical proximity to competitors. Furthermore, several scenarios with different strategy settings indicate that firms should prefer

to establish their own technological competencies and avoid coordinated behavior as this strengthens competition and reduces firm profits. Chapter 7 treats issues of economic policy. We begin by showing the technological development in scenarios which differ in the number of firms located in the agglomeration. We demonstrate that learning helps to increase average knowledge but isolation favors best-practice. Two archetypes of an innovative industry are examined in a section on technological regimes and the results approve structural differences of the technological development in the two scenarios. We then confront our virtual industry with interventions in the form of regional innovation policies. We consider four policy options which aim at increasing the incentive for geographical proximity, fostering learning, raising appropriability, and controlling specialization of the agglomeration. We detect large policy cost differences and potential conflicts between goals of several policies. In general we recommend a support of appropriability conditions and local learning mechanisms broadening the local knowledge pool. Problems of political influence on competition come in the form that mostly firms with lower technological capabilities are supported and that a better technological development is often connected to monopolistic tendencies.

Part IV summarizes the conclusions of the other chapters and returns to the research questions mentioned above. Finally, the limitations of our approach and potential extensions for future research are highlighted.

Part I

Motivation

Chapter 2

Foundations of Innovation and Proximity

This chapter introduces the main concepts which constitute the basis for the modeling approach and analysis of the model. We introduce arguments to underline the relevance of innovation and proximity and start in Section 2.1 by asking why innovations are important. We show that innovations are the driving force behind economic growth and that most innovations are established by private firms. This brings us to the topic of competition between firms in terms of knowledge and the potential transfer of knowledge through knowledge spillovers. At this point two different interpretations of proximity come into play. In Section 2.2 we investigate the influence of geographical proximity on innovation while studying the literature on local knowledge spillovers and agglomeration. The second aspect of learning is connected to the idea of technological proximity. Therefore, Section 2.3 sheds light on the discussion whether a specialized or a diversified environment promotes knowledge spillovers. Further we introduce our understanding of technological proximity as proximity between technologies, technological gap and its relation to a product space. But first, we want to explain why the notion of innovation has become so widely used by firm managers and politicians.

2.1 Innovation and Knowledge Spillovers

This book aims at understanding the process of innovation and technological change and its relation to proximity. In this connection innovation and technological change seem to be crucial for understanding economic growth (see e.g. Hall, 1994; Griliches, 1998) and continuing economic growth is one of the main goals of economic policy. For example the German Stabilitätsgesetz¹ promotes the fostering of economic

¹Das Gesetz zur Förderung der Stabilität und des Wachstums der Wirtschaft' established on June 8th, 1967.

growth. In order to justify this analysis it is important to define innovation, discuss its origin, and show its potential influence on economic growth.

Following Fagerberg (2005) it might be useful to differentiate between invention and innovation: "*Invention is the first occurrence of an idea for a new product or process, while innovation is the first attempt to carry it out into practice*" (Fagerberg, 2005, p. 4). This introductory article further mentions that both notions are linked to one of the most influential social scientists of the twentieth century: Joseph A. Schumpeter. In his work Schumpeter focuses on the role of innovation and its impact on social and economic change and in his view every new combination of existing resources represents an innovation. Schumpeter stresses the importance of dynamics and defines **innovation** as activities like the introduction of new products, implementation of new production methods, establishing of new markets, capturing of new sources of supply, and, finally, initiation of new ways to organize business (Schumpeter, 1912, pp. 100-101). Of the five types of innovation the first two especially, namely product and process innovations, are argued to be crucial for understanding technological development (Schmookler, 1966).

Another important distinction can be made between incremental and radical innovations. Freeman and Perez (1988) point out that incremental innovations occur more or less continuously in any industry and often result from proposals by users or from improvements suggested by engineers of production processes. Despite the incremental change of the product or production process the cumulative impact on the economy is often extremely important and leads to a steady growth of productivity. An example of an incremental innovation is the steady increase of quality and decrease of production cost of industrial products like airplanes or printing machines. On the other hand, radical innovations are more discontinuous events and usually emerge from intended research activities by firms and public institutions. Furthermore, radical innovations are often the "*potential springboard for the growth of new markets*" (Freeman and Perez, 1988, p. 46). For a certain time a radical innovation is connected to dramatic structural changes as new products and markets eliminate others, but their aggregated economic impact is rather small. If several radical innovations appear at the same time, and Schumpeter (1939) observed that they often do so, the overall impact on the economy can be quite large. For example a single radical innovation is nylon and the emergence of several synthetic materials created a whole new type of industry.

One of the most important questions in the context of innovation asks how innovations occur. In earlier times the emergence of innovations was understood to be a random phenomenon and a factor impossible to formalize in growth models like Solow (1956). Some scholars phrased it in the way that innovations fall like manna from heaven (Fagerberg, 2005). In the literature two opposing views concerning

the main source of innovation can be distinguished, see e.g. Hall (1994). The first science- or technology-push model argues that innovations originate in science and are later applied for commercial use. In line with this view is the linear model of innovation which differentiates between basic research, applied research, development, as well as production and diffusion (Bush, 1945). To the contrary the second market or demand-pull approach claims that only market demand determines the path for successful experimental and applied research (Schmookler, 1966). Other scholars argue that both factors are interlinked and that supply as well as demand side play a crucial role for innovations (Rosenberg, 1982).

Apart from the science-push versus demand-pull debate the properties of innovation found in several empirical studies highlight the role of knowledge as the main input factor of innovations. In the following we follow Döring and Schnellbach (2006) and define **knowledge** as the sum of all cognitions and abilities that individuals use to solve problems, make decisions and understand information.

For example the nature of innovation and its dependence on knowledge is analyzed by Dosi (1988a) where the author works out the following properties of innovation: Innovations always incorporate an element of uncertainty, rely on scientific knowledge, emerge due to search activities in formal organizations like firms rather than individuals, rest on informal learning processes, and technological change is a cumulative activity.² The characteristics of innovation are also connected to the concepts of technological paradigms and technological trajectories (Nelson and Winter, 1977; Dosi, 1982, 1988b). Hence, formal and informal research activities have an impact on the amount of knowledge, which again influences the probability for successful innovations.

Before we go into a deeper analysis of knowledge and learning we take a look at the relationship between R&D and economic growth. The analysis by Maddison (2001) postulates that economic growth really started only in 1000 AD after a long period of stagnation. Since then economic growth has been increasing, in particular after the Industrial Revolution. During and after the 1970s several economists studied the issue of economic growth in empirical studies, see Freeman (1994); Griliches (1998) or Verspagen (2005) for a recent overview. In these econometric models the relationship between the Gross Domestic Product (GDP) and knowledge in the form of R&D is examined and typical results yield that knowledge has a significant impact on productivity growth.

This approach is also taken in a recent study by Legler and Krawczyk (2007). One of their results is shown in Figure 2.1, where each point represents data of a country averaged over several years³. On the abscissa the change of real expenses

²In Section 3.3 it is debated that these properties have to be part of the theoretical model.

³Data points represent average value of years 1994 till 2004 for all except GBR, ITA, SWE

of R&D and on the ordinate the change of GDP is measured and all values are indicated in percent. The distribution of the data points and an estimated linear regression curve give evidence that expenses for R&D, which generate additional knowledge, favor growth of the economy. According to Fagerberg (2005) mainly two mechanisms underlie the causal relationship between innovation and economic performance: First, firms and countries compete mostly in technological competition, and second, innovations open up possibilities for further innovations, which leads to continuing structural and economic change.

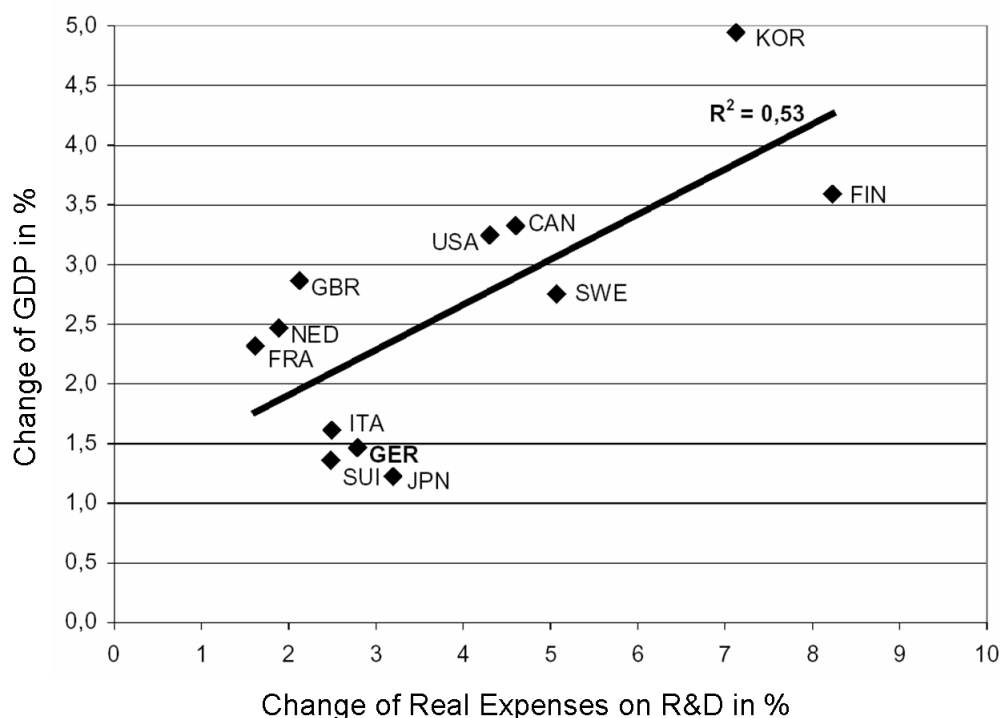


Figure 2.1: The relation between R&D and economic growth during 1994-2004 in the Group of Twelve. Source: Legler and Krawczyk (2007)

Taking the positive relation between R&D and economic growth into account we turn to the question whether public or private research activities are the main source of technological change. Fagerberg (2005) is convinced that inventions often emerge from public institutions like universities, while innovations are mostly introduced by private firms. This view is also supported by Cantwell and Fai (1999) who claim that the firm is the principal source of innovation and, henceforth, growth. Again, Dosi et al. (1994) believe that firms are the main locus of technological accumulation and Jensen and McGuckin (1997) conclude from a survey of empirical studies that firms are the main drivers of economic growth. For Schumpeter (in his earlier writings) small entrepreneurial firms (Schumpeter, 1912) or, at a later stage, which use data till 2003.

organized research and development in large firms (Schumpeter, 1942) are best suited to introduce innovations and hereby push the technological development. In both cases firms - not public research - play the major role. Hence, in order to deepen the understanding of innovation and proximity it may be justified to concentrate on the firm as the major origin of innovations.

Knowledge as a precondition for successful innovation is a possibility for a firm to differentiate itself from competitors and earn profits through this competitive advantage. In this view the heterogeneity of firms is crucial for competition. There is empirical evidence that firms indeed differ a lot, which has a major impact on their economic performance (Nelson, 1991; Jensen and McGuckin, 1997). In the management literature aspects of firm-specific knowledge have been highly discussed in recent years, see e.g. surveys by Zollo and Winter (2002); Fai (2003); Wang and Ahmed (2007). The debate is related to theories of the resource-based view of the firm (Penrose, 1995; Barney, 2001), organizational routines (Nelson and Winter, 1982), core competence (Prahalad and Hamel, 1990), absorptive capacity (Cohen and Levinthal, 1989, 1990), and, most recently, the concept of dynamic capabilities (Nelson, 1991; Teece and Pisano, 1994; Helfat, 1997; Teece et al., 1997).

The resource-based view of the firm can be traced back to the book by Penrose (1995) which was originally published in 1959. Here the firm is not only seen as an administrative unit but as a collection of productive firm-specific resources. These valuable, rare, inimitable, and non-substitutable resources of the firm enable a better standing on the market, but in order to exploit the resource advantages firms have to possess or develop certain capabilities. Both factors - resources and capabilities - constitute a competitive advantage (Wang and Ahmed, 2007). Later, the scientific focus of attention moved to competencies and technological competencies especially, which can be seen as a subset of the more general resource based approach. The set of technological competencies can be described as the firm's technological portfolio. Prahalad and Hamel (1990) argue, that the firm's economic performance is enhanced if it concentrates on particular areas of its technological portfolio - the so called core competencies. Nelson and Winter (1982) propose that essence of the firm's strength lies in routines, which is related to the concept of competencies. In their interpretation **organizational routines** stand for a set of rules or heuristics which capture the way things are typically done in the firm and which tend to persist. Firms develop routines over time from their own experiences and accumulated knowledge. The routines can be modified while firms scan their technological environment and search for opportunities on product markets (Fai, 2003). In the same way the potential of a firm to absorb external knowledge is stressed by Cohen and Levinthal (1990).⁴

⁴This will be further examined in Section 2.3 in the context of technological proximity.

During the 1990s the original propositions by the resource-based view of the firm was criticized as being static and neglecting market dynamism (Wang and Ahmed, 2007). As a reaction the theory of dynamic capabilities was developed which takes into account a rapidly changing environment incorporating the evolutionary nature of resources and capabilities (Teece et al., 1997). In conclusion both concepts agree in the importance of firm heterogeneity and that the ability to develop and sustain competitive advantage is crucial for the explanation of firm performance and its impact on technological change and economic growth. This is in line with the idea of Schumpeterian competition where firms with better capabilities to innovate grow at the expense of less efficient rivals (Schumpeter, 1912).

Empirical studies investigate whether specialization or diversification enhances the performance of firms. For example Montgomery (1985) shows that highly diversified firms in their markets have lower market shares than less diversified firms. Additionally, there is empirical evidence that in average highly diversified firms compete in less attractive markets. On the other hand, the empirical work by Garcia-Vega (2006) examines 544 European firms and indicates a statistically significant positive relationship between technological diversity and innovation at the firm level. The study by Pandya and Rao (1998) adds further detail to the debate as they indicate a trade-off between risk and return. The authors provide evidence that specialized firms earn higher profits than average, but these returns are accompanied by high variance, whereas diversified firms gain lower profits at much lower variance. Another approach (Duysters and Hagedoorn, 2000) explores the creation of core competencies and their effect on firm performance in the international computer industry. The empirical results support the importance of core capabilities for performance differences of companies in the high-tech sector. On the other hand, in their sample market specialization does not appear to have a positive impact on performance, which is explained with a continuing technological convergence in the computer industry.⁵ Further, the authors discovered several difficulties while acquiring a core competence through merger and acquisition or with the help of a strategic alliance. The difficulties to absorb external knowledge are discussed at some later point, but first we would like to introduce the concept of knowledge spillover in a more general way.

Having recognized the importance of knowledge assets for a firm the potential to learn from competitors, or the loss of economic valuable knowledge through externalities, becomes a major issue. The transfer of knowledge is discussed under the notion of technology or knowledge spillover. Although this book concentrates on knowledge spillovers between firms which are active in the same industry, knowledge spillovers also play a major role for the technological development of regions and even nations.

⁵See also Wuyts et al. (2005) for the same standardization argument in ICT.

For example Keller (2004) reports on page 752 that *"foreign sources of technology account for 90 percent or more of domestic productivity growth"*.

Other empirical studies approve the importance of knowledge spillovers at the firm, regional and national level, see e.g. the surveys by Griliches (1998); Keller (2004); Audretsch and Feldman (2004); Koo (2005); Döring and Schnellenbach (2006); Los and Verspagen (2007). For example Koo (2005) groups different empirical works according to the categories: Technology flow, cost function, production-function, and paper trail approach. The main finding of this strand of literature is that knowledge spillovers are relevant for firm strategy decisions as well as for regional innovation policy.⁶

We define **knowledge spillovers** as the voluntary or involuntary exchange of knowledge between individuals, firms, regions or countries. In this context knowledge can be incorporated in routines, ideas, methods, techniques or technologies. Further, exchange means that the flow of knowledge occurs always in two directions despite the fact that the result of the learning process can be quite different for the interacting agents. Further, sources of knowledge can be private R&D of firms or research by public institutions like universities, think tanks etc.

Knowledge spillovers are a form of a positive externality and knowledge itself is connected to the concept of public good: First, the same piece of knowledge can be shared by more than one firm at the same time (non-rivalry). Although there might be negative economic consequences the innovating firm is not limited in its usage of the technology (Koo, 2005). Second, it is hard to prevent unauthorized usage once it is in the open (non-excludability) (Los and Verspagen, 2007).

From a public policy perspective the discussion about knowledge spillovers has become very vivid with models of economic growth. The model by Solow (1956, 1957) develops a theoretical framework for economic growth which relies enormously on knowledge externalities. Here knowledge is seen as a pure public good, which has major consequences when looking at the research activities of firms and nations: The uncompensated flow of knowledge diminishes all incentives for a firm or to perform its own research. This 'market failure' implication is, however, not consistent with the empirical finding that private R&D has been increasing during the past several decades (Koo, 2005). In contrast to the early growth framework the endogenous growth model by Romer (1990) modifies the assumption in the way that technology is understood to be non-rival but only partially excludable. Other endogenous growth models like Grossman and Helpman (1991) or Aghion and Howitt (1997) also consider technological externalities.⁷ In the same line this book does

⁶The studies which are important for geographical and technological proximity are discussed in the following two sections and more details on regional innovation policy can be found in Section 7.3.

⁷See Section 3.1 for an overview.

not handle knowledge as a pure public good and we investigate potential barriers to knowledge externalities and their relation to proximity in Sections 2.2 and 2.3.

Going back to Scitovsky (1954) and Griliches (1979, 1992) one can often find the following differentiation of two types of spillovers in the literature (see also Koo, 2005; Los and Verspagen, 2007):

1. vertical, welfare, pecuniary, or rent spillover
2. horizontal, technological, non-pecuniary or knowledge spillover
 - (a) idea-creating knowledge spillovers
 - (b) imitation-enhancing knowledge spillovers.

The first type of rent spillover is connected to market interactions between supplier and user. The benefits of a new or improved product or lower production cost are often distributed between seller and buyer depending on the market structure. In case of a monopoly the firm can fully appropriate the benefits of the innovation and capture all economic rents. The stronger the competition or bargaining power the more a supplier is forced to transfer parts of the innovation rent to the user in the form of lower prices. Hence, the concept of rent spillovers highlights the appropriability problem of the innovator and rent spillovers are equal to an increasing price quality ratio (Los and Verspagen, 2007). Empirically it is difficult to measure these group of spillovers as price indexes do not correctly reflect quality improvements. An example is the computer industry with stagnating or only slightly decreasing prices accompanied by great advancements in the computer performance.

Krugman (1991b) refers to Marshall (1920) while indicating three potential forms of locational externalities: economies of specialization, labor market economies and knowledge spillovers. The first two forms are often referred to as pecuniary or rent spillovers in relation to localization externalities since they mostly work for agents of the same industry. In contrast to this the last type is seen as a true technological externality and is in principle useful for all members of the local community, which is connected to the term urbanization externality (Breschi and Lissoni, 2001a; Audretsch and Feldman, 2004).⁸

The second form of spillovers in our list is located at the heart of the interpretation in this book. Knowledge spillovers are related to the transmission of knowledge that results from the characteristic as a (partial) public good. Knowledge in this case is not embodied in goods but part of a general pool of knowledge and it may spill over between individuals or firms even in the absence of market interactions (Koo, 2005). Instead of a seller-buyer constellation the relationship here is based on

⁸This topic is further examined in Section 2.3.

technology linkages. Only these kinds of spillovers create further innovations and shift the production capacity of an economy (Griliches, 1992) as the knowledge stock of both firms may increase. Knowledge spillovers in this sense are true spillovers and, unlike rent spillovers, *"not just a statistical redistribution of productivity gains due to competition and measurement errors"* (Los and Verspagen, 2007, p. 4).

According to Los and Verspagen (2007) knowledge spillovers can be further grouped into idea-creating and imitation-enhancing spillovers. Through the first type of idea-creating knowledge spillovers new innovations and applications might emerge which need not be in the same technological field. The absorbed knowledge is transformed and applied to the current needs of the firm and this process might generate new knowledge. Therefore, idea-creating knowledge spillovers need not lead to an increase in competition. The situation is different in the case of imitation-enhancing knowledge spillovers. This form of knowledge spillovers addresses the transfer of mostly codified knowledge which may not be perfectly protectable. Competition in a market can be intensified if a firm imitates the production process or product characteristics of an advanced competitor. Patents are one way to economically protect innovators from imitation-enhancing but not from idea-creating knowledge spillovers. In both cases knowledge would still spill over from the innovator to rivals as patents prevent only the introduction of technologically similar products. Patent laws do not prevent the usage of knowledge for a technologically different product.⁹ Empirical observations by Levin et al. (1987) indicate that R&D managers indeed see patents not as the best alternative to protect competitive advantages of new or improved products or processes.

In the literature it is further discussed in what ways knowledge can spill over from an individual, firm, region or nation to another. During this debate several sources of knowledge spillovers are indicated and ranked by their relevance in case studies and broad empirical surveys. As a result the main channels of knowledge spillovers can be summarized as the following:¹⁰

- **Publications:** Patents, scientific literature, research reports, newspaper, website
- **People:** Face-to-face communication, mobility of R&D employees, employment of students, scientists, or consultants, spin-offs, training
- **Formal Co-operations:** Research joint ventures, communication with customers, users and suppliers

⁹There is of course a problem to define a technologically different product, see the literature on patent breadth, e.g. Gilbert and Shapiro (1990) and Encaoua et al. (2006).

¹⁰The sorting builds upon works by Levin et al. (1987); Arvanitis and Hollenstein (2001); Brenner (2007); Los and Verspagen (2007).

- **Informal Contacts:** Fairs, expositions, meetings, talks, presentations, demonstrations, communication with competitors
- **Products:** Reverse-engineering, licensing, acquisition of (capital) goods

The first potential channel of knowledge spillovers are publications. Apart from patents, which are probably one of the major ways for the diffusion of technical knowledge, other scientific or non-scientific announcements like an article in a local newspaper may provide the reader with crucial details about actual R&D activities. People in possession of knowledge can be another source of technology transfer, for example when they change their engagement or meet each other on formal or informal occasions. The importance of face-to-face contacts is highlighted in the literature and is connected to the exchange of ideas between people, see e.g. Audretsch (1998). Formal co-operations like research projects, or informal contacts can occur within a firm or between firms. The interaction through formal channels of communication with suppliers and customers can provide a lot of new impulses for the advancement of products. Also, conferences and fairs are indicated to be one of the most active occasions for the exchange of ideas for new products and processes (Maskell et al., 2006). Last but not least in relevance, the flow of knowledge through products is responsible for a large amount of knowledge spillovers between nations.

Although Levin et al. (1987) in their broad survey do consider acquisition of knowledge through licensing and independent R&D as sources of technology transfer, Los and Verspagen (2007) state that these activities cannot be understood as channels of knowledge spillovers. Further, several means of exchange of knowledge are connected to the concepts of 'being there' (Gertler, 1995) and 'local buzz' (Malmberg and Maskell, 2006). Foreign direct investments by multinational companies are also understood to be important channels of knowledge spillovers (Döring and Schnellenbach, 2006). Furthermore, in an empirical study of Belgian manufacturing firms Cassiman and Veugelers (2002) find that commercially sensitive knowledge often leaks out to competitors through shared suppliers or customers.

Empirical works try to identify which potential channels of knowledge spillovers are more important for the exchange of ideas. Among them is the article by Levin et al. (1987) indicating that reverse-engineering is the most important source of technology for high-level executives in US manufacturing companies. The effect is stronger for products, but reverse-engineering even seems to enable learning of better production processes. Furthermore, publications, technical meetings and hiring of R&D employees from innovating firms tend to be other sources for knowledge spillovers, which are even more useful than patents or conversation with employees. The empirical investigation of Arvanitis and Hollenstein (2001) ranks the sources of knowledge for Swiss firms in the following order: Communication with cus-

tomers/users, fairs/expositions, suppliers of materials/components, professional conferences/journals, recruitment of experts, competitors, suppliers of equipment, subsidiaries/mother firms, universities/technical schools, acquisition of capital goods, other government research institutions and patent disclosures, acquisition of other firms, technology transfer agencies, private scientific laboratories/consulting firms, government technology programs and acquisition of licenses. And recently Giuri et al. (2007) have performed a survey based on European patents and introduced six sources of knowledge used to develop innovation sorted by their marked importance from questionnaires: Customers and users, patent literature, scientific literature, competitors, technical conferences and workshops, suppliers as well as universities and public research laboratories.

The diverse channels of knowledge spillovers add to the importance of knowledge transfer. Building on the definition of knowledge spillovers in connection with the importance of knowledge assets for firm strategy, we recognize that knowledge spillovers can be a serious threat for a firm's market position. The question how to prevent knowledge spilling over to competitors in this context has to be tackled. If a firm wants to benefit from knowledge externalities and seeks possibilities to learn from advanced competitors, they always have to fear the loss of their own core competencies as learning always happens in both directions. This trade-off is often neglected in the literature¹¹, which understands knowledge spillovers as a solely 'positive' externality. The model introduced in Chapter 4 is based on this consideration of potential benefits and risks associated with knowledge spillovers. This topic is also taken up in the next section.

Levin et al. (1987) note that lead time and secrecy open a time window for the successful innovator to earn economic profits to finance previous R&D investments. Indeed Mansfield (1985) shows that there is no clear protection against knowledge spillover. The author reports in his investigation of 100 American firms that in average technological information concerning development decisions leaks out to rival firms within 12 to 18 months and details about a new product or process within one year. The flow of information occurs through the previously discussed channels of knowledge spillovers. Furthermore, process innovations in general diffuse much more slowly than information about new products. The author argues that this happens because of less external communication requirements in the case of process innovations. The time interval till competitors learn about the innovation is very short in relation to the time it takes to develop and commercialize an innovation, which was estimated by Mansfield (1985) to be about three years. That means that the decision information leaks out before the innovation project is half completed. Of

¹¹Positive exceptions are: Martin and Sunley (2003); Boschma (2005a); Iammarino and McCann (2006).

course the imitator needs additional time till he is able to introduce his own product on the market, but the time window for appropriating benefits from innovation is very limited.

Summing up, we put forward the argument that knowledge as the major input factor for innovation is significant to understand competition between firms and the technological progress of countries. Furthermore, because of the partial public good characteristic of knowledge it may diffuse to others through several channels, which may have considerable economic consequences for the creator. But, using a similar formulation as Keller (2004), knowledge spillovers are neither inevitable nor automatic: Own technology investments and aspects of closeness are needed to understand and apply external knowledge. At this point the interpretation of proximity comes into play and we argue that geographical and technological proximity are fundamental to assess knowledge spillovers.

The main idea behind knowledge spillovers and proximity is the insight that innovative learning is local. Localized learning in this sense is bounded to local conditions and spatial closeness (Malmberg and Maskell, 2006) as well as to the existing knowledge base and capabilities of processing knowledge (Antonelli, 1995), which is also related to the notion of technological paradigm (Dosi, 1988a). The first concept is debated under the notion geographical proximity and the latter under technological proximity. Both types of proximity and their relation to innovative learning are discussed in greater detail in the following Sections 2.2 and 2.3.

But before doing so we mention that other forms of proximity are also relevant for learning. Apart from geographical and technological proximity Boschma (2005a) and Knobon and Oerlemans (2006) deal with cognitive, cultural, social and institutional proximity. In line with Knobon and Oerlemans (2006) these four forms of proximity can be integrated into one, namely organizational proximity. Organizational proximity, in the view of Rallet and Torre (2000); Torre and Rallet (2005) and Knobon and Oerlemans (2006), is seen as the set of shared routines, values, norms, and cultures which allow for coordination and simplify communication between actors. This set incorporates organization structure, culture, institutions and social relations. As we do not explicitly model organizational proximity, we want to argue how this can be justified and why - at least in a first step - we abstract from this form of proximity.

In our view there are three reasons for not considering organizational proximity in the model: First, parts of the interpretation behind organizational proximity are related to and, hence, captured in the two basic forms of geographical and technological proximity. In contrast to Knobon and Oerlemans (2006) we see a strong overlap behind our interpretation of technological and cognitive proximity since both trigger the resulting learning effect with given knowledge bases of the actors. Further, it is

claimed that cultural, social and institutional proximity are strongly connected to geographical proximity (e.g. Maskell and Malmberg, 1999; Malmberg and Maskell, 2006). Those four types of proximity, according to Boschma (2005a), are all mechanisms that bring actors together and are henceforth substitutes. Therefore, parts of organizational proximity can be found in the formalization of geographical and technological proximity and need not to be modeled on their own. Second, in the description of geographical proximity the introduction of organizational proximity would not lead to a substantial change but only to a re-interpretation of the model. This happens because the decision for geographical proximity considers only two possibilities: In the agglomeration or outside.¹² The term agglomeration can be exchanged with club, group, community, or organization to re-interpret the model in a way that social, institutional, or cultural proximity is investigated. A proper examination of these forms of proximity cannot be done with minor changes - rather it needs an extensive reformulation of the model. Third, a quantification of proximity effects in economic terms can only be done in relation to consumer preferences, which is here achieved through a mapping from product to technology space. Thus, for an economic model it makes sense to concentrate on the technological and only one further dimension of proximity. Doing so keeps the model as simple as possible and still allows to capture relevant aspects.

We close this section with the insight by Boschma (2005a), who argues that geographical proximity alone is not sufficient and it requires at last cognitive (or technological) proximity to assess learning processes in a useful manner. Further, we are interested in the relatedness between those two forms of proximity or as Antonelli (2007) formulates on page 259: *"Proximity in geographic space interacts with proximity in knowledge space."* We agree and continue with the description of the relation between innovation and geographical proximity in the next section.

2.2 Innovation and Geographical Proximity

There is a long lasting tradition in the literature on the influence of geographical proximity on innovation, although in early days Schumpeter was not concerned with spatial aspects of innovations and agglomeration theory was not dealing with innovations. This changed during the last decades and now many authors claim that there is a deep connection between innovation and space (Simmie, 2005). Geographical proximity and innovation today is a very vivid field of research, which can be seen in several surveys and special issues on this topic. Despite the fact that all literature overviews handle both (empirically and theoretically oriented approaches), examples for more empirically oriented surveys are: Breschi and Lissoni (2001a);

¹²See Sections 4.1.3 and 4.3.3 for more details.

Audretsch and Feldman (2004); Koo (2005); Döring and Schnellenbach (2006); Los and Verspagen (2007). Of the more theoretically oriented reviews the following can be mentioned: Audretsch (1998); Moulart and Sekia (2003); Döring (2004); Simmie (2005); Malmberg and Maskell (2006); Iammarino and McCann (2006).

Instead of geographical proximity synonyms like territorial, spatial, local, or physical proximity are used. Apart from the physical distance between two individuals, firms, or regions our definition of **geographical proximity** also contains, as noted by Knobens and Oerlemans (2006), the probability or extent to which two agents can have daily face-to-face contact without prohibitive costs. This is assumed to have a positive influence on learning through knowledge spillovers.

We might start with writings of David Audretsch (e.g. Audretsch, 1998), in which the author investigates the potential discrepancy between an increasing globalization, arising from the computer and telecommunication revolution in combination with falling transport costs, and the relevance of the geographical location of companies. In contrast to an often proposed public opinion which points to the unimportance of locational factors, several economists and economic geographers still see the significance of firm location and industry concentration in the present as well as in the future (e.g. Storper and Scott, 1995; Porter, 1998; Glaeser, 1998; Porter, 2000). Hence, in order to lay the foundations of the economic model we have to answer the question: Why is geographical proximity - even in an age of long-distance mass communication - still relevant?

At first glance the choice of firm location would be driven by consideration of wages as well as factor, production and transport cost arguments (Weber, 1909). But in the long run the capabilities to increase one's own productivity and attract new customer groups to one's own products are understood to be major determinants of the economic success of a firm (Porter, 1998).¹³ Both aspects are related to innovations: First, process innovations enable the reduction of production cost and second, product innovations allow a better meeting of consumer needs with advanced or new products and services. As argued in the previous section, the capability to innovate is driven by the input factor knowledge. But the production factor knowledge is rather different from the traditional factors of production - labor, capital and land - because it is to a high degree uncertain and often asymmetrically distributed among agents (Nelson, 1991).¹⁴ Additionally, knowledge can be transmitted from its source across geographical space without losing any economic value. But this flow of knowledge is to a certain degree bounded and knowledge is not a pure public good. We argue that the first frontier of knowledge spillovers is geographical distance despite

¹³See also the debate of firm strategy and dynamic capabilities in the previous Section 2.1.

¹⁴Alfred Marshall also highlights the role of knowledge, but he regards it as a part of capital (Marshall, 1920, p.138).

the existence of fax, telephone, email and the world wide web.

The crucial point for the argument is the distinction between information and knowledge (Audretsch, 1998; Audretsch and Feldman, 2004), which was already mentioned by Jacobs (1969). On the one hand, information such as the price of a Siemens stock on the Frankfurt Stock Exchange or the exchange rate of Euro to Dollar can be easily codified and exhibits a singular meaning and interpretation. The telecommunication revolution has indeed drastically reduced cost and increased speed and availability of information. On the other hand, knowledge is characterized as vague, difficult to codify and seldom recognized as such (Dosi, 1988a). This so called tacit knowledge (Polanyi, 1966) is difficult to formalize or write down and is often embodied in people. Therefore, tacit knowledge is best transmitted from face to face (von Hippel, 1994; Gertler, 1995). Examples of tacit knowledge are learning to swim or to ride a bicycle. Hence, geographical proximity leads to a higher possibility for direct communication between individuals, which favors the exchange of tacit knowledge.

Apart from the ease of transmitting knowledge it should be mentioned that some results are not published or codified at all. For example the failure of a scientific experiment does not have good chances to get published although it might be of great interest for people working in the same field. This knowledge might only spill over by face-to-face contact between directly interacting people. Further, the local social and organizational environment is understood to favor learning and asks for a concentration of research activities on a single adequate spot (Asheim and Gertler, 2005). In the same way Malmberg and Maskell (2006) stress the localized capabilities and conclude that interactive learning is a localized process.

The relation of spillovers and tacitness is not accepted by all writers in the area of research. Breschi and Lissoni (2001a) discover a conceptual problem which makes it difficult to fully understand the role of geographical proximity in knowledge transmission. Howells (2002) points out that in Polanyi's view explicit (or codified) and tacit knowledge are not divided but should be seen rather as two extremes which open up a continuum of many types of knowledge. Further, Torre and Rallet (2005) criticize the thesis that geographical proximity leads to the sharing of tacit knowledge whereas codified information can be accessed even from long-distance relations, as being too simplistic. Like Howells (2002) they are convinced that information and knowledge are difficult to separate. Furthermore, the authors find that other forms of proximity like organizational proximity¹⁵ can support the long-distance coordination and that new technologies like chats, forums, or video-conferences become close to oral communication. Nevertheless, Torre and Rallet (2005) see the importance of face-to-face relations for innovative projects and for solving conflicts between

¹⁵See the debate on different types of proximity at the end of the last section.

innovators. During these activities firms need to adjust their localization and seek temporary¹⁶ or permanent geographical proximity to the innovators.

The differentiation between knowledge and information asks for a second look at the channels of knowledge spillovers introduced on page 16 as some of these channels are more local than others. Information in newspapers or on websites diffuses very fast but tacit knowledge uses more local channels like personal contacts (Döring and Schnellenbach, 2006). Tacit knowledge is also incorporated in patents or other scientific publications and apart from the publications themselves one might need further explanations to really understand the content, which results from the fact that not all relevant details are (or can be) codified. This may even be true in the case of codified knowledge as its interpretation and assimilation may still require tacit knowledge and, thus, geographical proximity (Howells, 2002). Hence, geographical proximity also favors the distribution of codified knowledge.

Especially, firms will avoid the publication of knowledge that is particularly relevant for process or product innovations. The fact that the source of new knowledge matters for knowledge spillovers is one out of three conditions for the diffusion of knowledge elaborated by Caniëls (2000): Source of knowledge (private or public), capacities and willingness of the recipient of new knowledge, and the relationship between the recipient and the source of the new knowledge. In contrast to firms public sources of knowledge (e.g. universities) are in general more willing to publish and circulate their research results because many and qualified publications add to the reputation of the researcher and institution. The second condition incorporates aspects of technological, and the third of geographical proximity.

Malmberg and Maskell (2006) argue that learning is indeed localized as it profits from regular and direct face-to-face contacts and the communal sharing of cognitive and social repertoires. In the horizontal dimension, which concerns competing firms operating in the same industry, two effects for localization are distinguished by the writers: Observability and comparability. First, closely located firms undertaking similar activities may benefit from regular monitoring or even spontaneous observations that reveal every difference in the market behavior of the rivals. Second, the sharing of common conditions, opportunities and threats displays the strengths and weaknesses of myself and the competitors. Therefore, geographical proximity helps firms to identify and imitate best-practice as well as to combine external superior solutions with ideas of their own. Similar arguments about localized learning in clusters can be found by Caniëls and Romijn (2003) and Dahl and Pedersen (2004).

According to Malmberg and Power (2005) firms in an agglomeration do not only

¹⁶For more details on the interpretation of temporary proximity please refer to the end of this section.

benefit from knowledge spillovers but may also create additional new knowledge.¹⁷ The authors analyze the empirical literature on clusters to identify potential mechanisms of knowledge creation and evaluate them upon their empirical relevance. We summarize their results in the following listing, where we mark the mechanism of knowledge creation by '+' if there is empirical evidence for the result and by '~' if the empirical support is very little or ambiguous:

- **Knowledge through interaction:** Inter-firm business transactions (~) and non-transactional forms of inter-firm collaborations (~)
- **Knowledge through competition:** Local rivalry (~)
- **Knowledge through knowledge spillovers:** Social relations (+) and labor market flows (+)

The first finding of Malmberg and Power (2005) does not support the view that formal interaction between firms in an agglomeration is important for the creation of knowledge. Some firms report that for their most important suppliers and customers not local but global networks dominate. The positive effect of increased competition in clusters put forward by Porter (1998) is only investigated by few studies and, thus, there is only little support for the thesis that clusters enhance local rivalry. It is striking that both considered channels of knowledge spillovers in the form of social relations between individuals and local labor mobility are supported by empirical evidence. The latter is even indicated by firms as inducing more problems than generating advantages. The authors conclude that knowledge creation in clusters happens mostly not by organized inter-firm transactions and collaborations but rather by rivalry, labor dynamics and informal contacts creating knowledge spillovers.

As overall conclusion from the mentioned examples and empirical surveys cited at the beginning of this section the following can be proposed: Although there is some critique on the methodology of measuring knowledge spillovers (Breschi and Lissoni, 2001a), empirical evidence suggests that geographical proximity clearly matters in exploiting knowledge spillovers (Audretsch and Feldman, 2004). Or as Döring and Schnellenbach (2006) formulate on p. 383: *"[T]here appears to be a widespread consensus that spatially confined knowledge-spillovers are an important empirical phenomenon with a significant impact on economic performance"*. Among the key contributions which constitute this finding are the works of Jaffe et al. (1993), who find that the trails of knowledge spillovers found in patent data are geographically localized, Audretsch and Feldman (1996b), who stress the importance

¹⁷See also the idea-creating type of knowledge spillovers in Section 2.1.

of the geography of innovation and production, and Zucker et al. (1998), who discover the influence of top scientists on the clustering of high technology firms.

Some of the empirical studies can even provide a clear range of knowledge spillovers. For example Anselin et al. (1997) propose that knowledge of university research mainly spills over 50 miles away from the innovating metropolitan statistical area, see Döring and Schnellenbach (2006) on p. 384 for several other examples. An interesting illustration of the geographical range of knowledge spillovers is worked out by Peri (2005) and is shown in Figure 2.2. In his empirical study, which estimated knowledge flows on the basis of 1.5 million patents from Europe and North America during 1975-1996, the author finds evidence that only 20% of knowledge is in average acquired outside the region and 9% outside the country of origin.

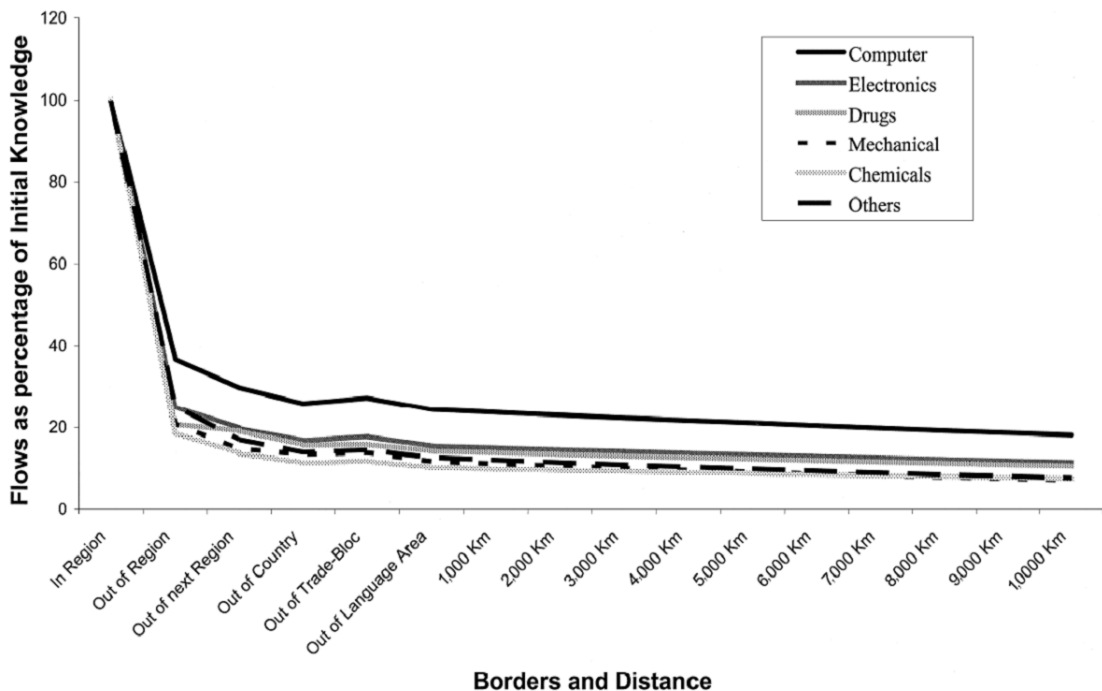


Figure 2.2: Decay of knowledge spillovers by technological class. Source: Peri (2005)

The decay of knowledge flows of several technologies in geographical space is depicted in Figure 2.2. Here we see that the range of diffusion is by far greatest in the computer industry. Despite the fact that less than 40% of knowledge in average leaves the region of origin and approximately 25% of this knowledge flows out of its country and linguistic area, computer technology appears to have a more global scope of research (Peri, 2005). The knowledge flows in the other sectors are much more localized and it seems that knowledge in electronics and drugs sectors spreads farther than in the mechanical or chemical sector. As with all proposed borders of knowledge flows the methodology can be criticized in the way that the range is often given through statistical areas (Döring, 2004) and statistical state boundaries

are maybe a poor proxy for geographical units of the knowledge circulation (Breschi and Lissoni, 2001a). Nevertheless, the visualization of possible borders of knowledge spillovers, which are statistical results and may not hold in the individual case, help to stress the fact that learning is indeed localized.

Apart from the empirical works on innovation and geographical proximity there is also a substantial theoretical literature on agglomeration and its relation to innovation. For an overview of the historical development we refer to Rocha (2004) or Simmie (2005) and an attempt of a graphical representation of the related theories is provided by Moulart and Sekia (2003).

The topic of innovations and geographical proximity is debated under several notions like the following:

- Polarization Theory (Myrdal, 1957; Hirschman, 1958)
- Growth Poles (Darwent, 1969; Richardson, 1976)
- Cluster (Porter, 1990, 1998)
- Innovative Milieu (Camagni, 1995; Ratti et al., 1997)
- Industrial District (Becattini, 1990; Dei Ottati, 1994)
- Proximity Tradition (Kirat and Lung, 1999)
- Regional Systems of Innovation (Cooke et al., 1997)
- New Industrial Spaces (Scott, 1988)
- Learning Region (Morgan, 1997)
- Localized Knowledge Spillovers (Breschi and Lissoni, 2001a; Caniëls and Romijn, 2003)
- Localized Learning (Malmberg and Maskell, 2006).

This diversity of theoretical approaches leads some scientists to claim that - although using similar concepts - spatial innovation models suffer from conceptual ambiguity (Moulart and Sekia, 2003). The classification of agglomerations and introduction of 'brands' for new strands of the literature is not seen to be very helpful and often generates misunderstandings (Breschi and Lissoni, 2001a,b; Martin and Sunley, 2003; Doloreux and Parto, 2004; Alecke and Untiedt, 2005). In particular the cluster concept of Porter (1998) is criticized by Martin and Sunley (2003) as being deliberately vague to admit a very wide spectrum of topics. Further, Overman (2004) argues that the literature on agglomeration could gain from the usage

of formal models, which help to identify crucial assumptions and enforce internal consistency, and rigorous empirical testing of the theory predictions. He is convinced that economic geographers may benefit from standard economic methodologies in order to clarify the relevant mechanisms as well as to develop a better theoretical and empirical foundation of their ideas.

As background for our model in Chapter 4 the differentiation of spatial innovation models is not of major interest since all of the mentioned works underline the positive effect of geographical proximity on the exchange of knowledge. The varieties of the several approaches is not (and probably should not) be modeled in order to concentrate on elementary aspects. For example the complexity of a regional innovation system can hardly be captured in analytical terms, which, in spite of more freedom in the design, also holds in the case of a simulation model. Hence, for the purpose of this book agglomeration, cluster, and geographical proximity are used as synonyms. However, the main insight that geographical proximity favors knowledge spillovers is taken as a crucial assumption for the formalization of the model.

On the other hand, the acceptance of spatially bounded knowledge spillovers implies that geographical distance might be a good protection against the loss of knowledge. Competition considerations are also an important factor in determining which firms decide to enter a cluster in the first place as knowledge spillovers always flow in two directions. Thus, a firm cannot prevent knowledge from spilling over to possible competitors in the cluster and a firm inhabiting a particularly profitable market niche or enjoying a technological lead might have strong incentives to choose geographical isolation on the periphery rather than joining a cluster. This constitutes the trade-off between learning and secrecy and it becomes obvious that knowledge spillovers might be both - a centripetal and a centrifugal force.¹⁸

This context is very clearly addressed by Iammarino and McCann (2006), who look at knowledge spillovers from two different perspectives, namely knowledge inflows and knowledge outflows. They argue that it is consensus that knowledge inflows are regarded as positive for all firms. Contrary, knowledge outflows can have both positive and negative consequences on the firm. A positive effect could emerge if unintentional knowledge outflows contribute and strengthen the local knowledge base. In that case other innovative firms may be attracted, which leads to larger knowledge inflows to the firm in the future. This positive effect is contrasted by the unintentional knowledge outflow of its valuable intellectual capital and intangible knowledge assets. We previously discussed (in Section 2.1) that the loss of knowledge assets might have very negative consequences on the profitability of firms as intellectual capital can be used to differentiate the firm's own products and earn

¹⁸See Krugman (1996) and Fujita and Thisse (2002) for the interpretation of centripetal and centrifugal forces in geographical terms.

innovative rents as well as to provide access to technology exchanges, joint ventures, and R&D collaborations (Grindley and Teece, 1997).

There are some case studies and empirical works supporting the view that firms avoid agglomerations because of the threat of unintentional knowledge spillovers. For example Suarez-Villa and Walrod (1997) find empirical evidence that not being located in a spatial cluster may be beneficial as firms are able to safeguard their privacy and introduce new products earlier than their competitors. The authors study the electronics industry in the metropolitan area of the Los Angeles basin, where many locational alternatives are available and not being located in a cluster may allow greater strategic flexibility. They find in their sample that profitability and productivity were significantly lower for the clustered establishments. Further, non-clustered establishments spent more on R&D and achieved greater economies from the introduction of just-in-time and outsourcing activities than clustered establishments. The authors conclude from their observations that not being located in a cluster may have been an advantage as some firms manage to maintain independence and secrecy for their R&D activities and that many small, independent, and R&D-intensive firms may have sought locations away from the larger producers found in clusters. Other case studies report a tendency for dominant firms in their industries to locate away from clusters. For example, Microsoft is located in Redmond / Washington and IBM developed its own personal computers in Boca Raton / Florida - both quite far away from Silicon Valley. Further, George Lucas' Industrial Light and Magic is located near San Francisco and not in Hollywood (Audretsch, 1998; Nachum and Wymbs, 2002). Other empirical studies with the result that technologically advanced firms avoid agglomerations are: Rauch (1993); Simmie (1998); Cantwell and Santangelo (1999); Shaver and Flyer (2000); Chung (2001); Kalnins and Chung (2004); Nachum and Wymbs (2005); Alecke et al. (2006).¹⁹

There are of course also other counter-arguments for choosing a location in a cluster, such as congestion cost like increasing land price, labor shortage and cost, environmental problems or even a technological lock-in due to over-specialization²⁰ (Martin and Sunley, 2003). These factors and the potential drawbacks of knowledge spillovers are often not considered in the literature despite their significance for the analysis of innovation and geographical proximity. In this work we abstract from all locational factors but learning through knowledge spillovers and concentrate on its impact on the economic competition. This endeavor is interesting and can be justified because knowledge spillovers can at the same time be convincing for one firm and deterring for another firm to settle in an agglomeration.

A critical matter of discussion about this argument could be the fact that firms

¹⁹Some of these studies are introduced at greater length in Section 6.2.

²⁰See Sections 6.3 and 7.3 for a longer discussion on this issue.

in reality do not change the geographical location of their research activities, which are often conducted in their headquarter. The following question arises and needs to be tackled: Do firms really change their geographical proximity in order to benefit from or avoid knowledge spillovers?

There exist some empirical studies which look at the location choice of newly founded firms. Buenstorf and Klepper (2004) and Klepper (2004) argue that spin-offs typically remain at the location of the former parent organization. It is shown that only a small percentage of the newly founded firms survive but a small part of the surviving firms is fast-growing, mainly responsible for new job creation, and additionally reveals very high locational dynamics, within as well as outside their region of origin (Stam, 2006). In the latter work the probability for a locational change of a firm in the considered knowledge-intensive industries rises with prior knowledge and experience of the founders, with autonomy of local resource providers and customers, and with less dependency on sunk cost. On the other hand, there is some evidence in Dumais et al. (2002) that new firms are more likely to start away from current geographic centers of the industry and growth is faster away from those centers, which in combination reduces the degree to which industries are geographically concentrated. Another very striking result of this study of U.S. manufacturing industries during 1972-1992 is the fact that concentrated industries appear to be fairly mobile. The fact that concentration emerges not simply from never moving industries is seen to be compatible with the view that externalities have a major influence on the levels of geographic concentration.

Some authors indeed argue that firms, and in particular multinational firms, have become very active in geographical terms. Firms increasingly establish new plants or branches in other places or foreign countries and regularly shift economic activities between their branches, which leads to a sharp rise of foreign direct investments during the last decades (e.g. Venables and Navaretti, 2004). In the same line Cantwell and Santangelo (2002) report that multinational enterprises disperse their innovation activities geographically across a range of locations to access foreign centers of excellence. Hereby, the multinational firms target certain agglomerations where they can enjoy local externalities including knowledge spillovers.

Taking into account that not only firms but also whole industries can be mobile in space, we further extend our interpretation of geographical proximity in two ways. First, we state that geographical proximity incorporates aspects of *temporary spatial closeness*. Second, we do not only understand the notion of geographical proximity as one particular geographical location of all R&D of a firm but more as a general *innovation strategy* which represents the general openness of a firm toward competitors or external learning. These two extensions of geographical proximity need to be assessed in more detail.

First, the relevance of temporary geographical proximity is highlighted in recent contributions to the literature (Torre and Rallet, 2005; Knoblen and Oerlemans, 2006; Maskell et al., 2006). This notion implies that interacting agents need not be in permanent spatial closeness, but that meetings, short visits and temporary geographical proximity can be very intense forms of knowledge exchange. Furthermore, it is stressed that the importance of geographical proximity for learning during a R&D project is not constant. Face-to-face contacts are more needed in certain phases of an innovative collaboration, such as during initial negotiations and launch of innovative projects (Rallet and Torre, 2000), during the creation and exchange of fundamental and tacit knowledge (Knoblen and Oerlemans, 2006), or during conflict management between innovators (Torre and Rallet, 2005). Further, Torre and Rallet (2005) are convinced that the increasing mobility of men, which points at the increasing significance of temporary proximity, is often neglected or underestimated in the literature. The authors report that in France the number of people working outside their home in a fixed location dropped by 4% and the number of workers travelling as part of their work increased by 40% during 1982-1994. The travelling of sales representatives, maintenance engineers, consultants, researchers, scientists, and even private visits also contribute to temporary geographical proximity. Hence, the constraint of geographical proximity, which is needed for knowledge spillovers, can be fulfilled temporarily through travelling without permanent co-localization of the partners (Torre and Rallet, 2005, p. 53).

In line with these observations the main focus of Maskell et al. (2006) lies on trade fairs, exhibitions, conventions, congresses, and conferences and their similarities to (temporary) clusters. The authors put forward the argument that these phases of temporary geographical proximity help business people and professionals to compare their products, investigate innovation efforts of competitors, identify knowledge frontiers and monitor customer reactions. The mechanisms at work during these short-lived and intense meetings are indeed comparable to knowledge creation processes in agglomerations and, hence, favor spatially bounded knowledge spillovers. Maskell et al. (2006) conclude that active participation in temporary clusters might provide solitary firms access to distant markets or knowledge pools without establishing a geographical location. Additionally, temporary clusters appear to be complements rather than substitutes to local learning in agglomerations as they introduce new knowledge to the local knowledge base. See also Bathelt et al. (2004) for potential benefits of global pipelines for clusters. Both phenomena show that geography matters - in permanent or temporary form.

According to Torre and Rallet (2005) the size of firms seems to have an impact on the possibilities for temporal localization. Big firms can more easily adjust their geographical proximity by de-localizing part of their innovative staff for long

intervals, whereas small firm do not have the same potential and are often forced to adopt permanent co-location in order to benefit from external knowledge flows. This sending of teams of researchers or the build-up for foreign research centers as part of the firm strategy brings us to the other extension of geographical proximity.

Second, the notion of geographical proximity can take another interpretation in the way that it describes the willingness and general openness of a firm to participate in knowledge exchange activities. Examples of such knowledge exchange efforts of firms, which do not hinge on the geographical location of the headquarter, are the affinity of firms to visit fairs and conferences (see above), to initiate research joint ventures with competitors, or to arrange for external research facilities like R&D labs in knowledge intensive clusters. Further, this willingness can change depending on the knowledge within the firm and the potential learning effect from such innovation activities. For example, after the introduction of a radical product or process innovation the firm might choose secrecy and not to participate in learning activities in order not to communicate about its technological breakthrough. In times when competitors appear to have a knowledge lead the firm might choose to be more active and seek every opportunity to absorb external knowledge. While doing so the firm itself produces knowledge outflows and offers to become an active member of the knowledge exchange group. For example knowledge incorporated in patents can be used to establish research joint ventures (Teece, 1998). In our view an open research strategy is therefore equal to a location in geographical proximity whereas a closed research strategy stands for a location on the periphery. In the first situation the firm puts more weight on external learning possibilities, in the latter on secrecy of its own research results.

A similar interpretation of geographical proximity like our second aspect is used in a simulation model by Muller and Pénin (2007). In their model each firm possesses knowledge held secret. This knowledge can be made available to others according to a parameter which describes the open knowledge disclosure strategy of each agent. The strategies can also be interpreted as being either more focused on current profits or more long-term oriented. The more knowledge is disclosed, the lower the profits, but the higher the reputation of a firm, which may enable more R&D cooperative relationships in the future. The trade-off in their work is indeed very similar to the main theme of this book, but a shortcoming of this model can be identified in its not considering aspects of absorptive capacity (see below) or not modeling market interactions with consumers. Nevertheless, the results are interesting as they indicate that there might exist a rationale for behaviors of open knowledge disclosures despite the fact that such strategies reduce profits in the short run, but pay out in the long run because the increased reputation enables firms to access external sources of knowledge in the future. As in the case of temporary geographical proximity it

can be very easily argued that the change of strategy can be made much more easily and faster than the change of geographical location of the whole firm.

Summing up the ideas of the last paragraphs we answer the above question: Yes, firms can very abruptly alter their geographical proximity to competitors. In our interpretation this does not necessarily mean that the firm moves its headquarter to another site. Geographical proximity can also be adjusted through the presence at events like fairs and conferences, the openness of one's own R&D strategy in terms of knowledge exchange with competitors, and the founding or closing of external R&D facilities. The decision upon these activities can be made in no time and is immediately effective. The choice of geographical proximity depends on the amount and structure of the firm's knowledge base which determines the level of knowledge in- and outflows.

The amount and structure of the knowledge base is related to technological proximity. How this determines the results of learning is the topic of the next section.

2.3 Innovation and Technological Proximity

The flow of knowledge is not only influenced by geographical but also by technological proximity. In order to assess the topic of innovation and technological proximity we start by looking at the technological environment and ask whether a specialized or diversified surrounding increases knowledge spillovers. After that, we concentrate on our interpretation of technological proximity which completes the foundation of the model.

One of the main points of interest is the question which regional setting is best suited as an incubator for technological change and further concentration of economic activity: Specialization or diversification of the local economic operations (Desrochers, 2001). Accordingly, the degree of technological specialization of an agglomeration should be of relevance for the intensity of knowledge transfer. Several authors have studied the impact of technological specialization on local knowledge spillovers, see e.g. Audretsch and Feldman (2004) but also earlier works like Hoover (1937) and Lösch (1940). See the following articles for recent reviews of the debate: Audretsch and Feldman (2004); Koo (2005); Ejeremo (2005); Döring and Schnellbach (2006); van der Panne and van Beers (2006).

There are mainly two competing hypotheses on the nature of knowledge externalities. As put forward by Marshall (1920), Arrow (1962), and Romer (1986) - later labeled by Glaeser et al. (1992) as the Marshall-Arrow-Romer (MAR) model - the specialization hypothesis argues that knowledge tends to be industry-specific. Hence, spillovers are expected to arise between firms within the same industry and

the similarity of knowledge and activities promotes learning between individuals and firms. Regional competition and specialization favor local knowledge spillovers among similar firms. These intra-industry spillovers are known as localization or specialization externalities.²¹ Empirical support for these claims was given e.g. by van der Panne (2004) or Ejeremo (2005).

By contrast, the alternative hypothesis proposes that knowledge spills over between complementary rather than within industries. As argued by Jacobs (1969) the exchange of complementary knowledge across economic agents enhances learning and leads to a cross-fertilization, which again fosters innovations. Ideas developed by one industry can be useful for other industries and, therefore, technological diversity favors knowledge spillovers. According to her a variety of industries within an agglomeration promotes knowledge externalities and a diversified regional production structure is expected to increase local knowledge and to give rise to urbanization or diversification externalities. Following this argument knowledge spillovers mostly happen between firms of different industries. As in the case of specialization externalities the diversity thesis is supported by empirical works, too. Examples are Feldman and Audretsch (1999) or van Oort (2002). In a study of German data from 1993 to 2001 Suedekum and Blien (2005) see empirical evidence that Jacobs externalities are relevant both in manufacturing and service industries whereas MAR externalities matter only in services.

Several other authors do not approve of either specialization or diversification, but take a middle position or see the importance of both types of knowledge spillovers depending on the type of innovations or the stage of product development. A recent study by Cantner and Graf (2004) provides further empirical indication concerning specialization and cooperation. In their work cooperation is measured by the number of participating firms on assigned patents. The authors find that technological moderately specialized regions show the highest number of research cooperations, and the higher a region's specialization, the more cooperations are formed between partners outside that region. Taking cooperations as a proxy for knowledge spillover, this results indicates that the exchange of knowledge is highest in moderately specialized clusters. A similar finding is provided by Fritsch and Slavtchev (2007), who suggest an inverted u-shaped relationship between regional specialization in certain industries and innovative performance. According to their German data from 1995 to 2000 a high specialization as well as great diversity of the sectoral structure in a region might reduce innovative performance. Hence, these papers argue against an extremely specialized or diversified technological environment.

Further, it is argued that firms with focus on incremental innovations benefit mostly from intra-industry knowledge spillovers whereas firms with focus on radi-

²¹See also the differentiation between localizational and urbanization externalities on page 15.

cal innovations benefit more from inter-industry knowledge spillovers (Döring, 2004; Döring and Schnellenbach, 2006). The hypothesis that both types of knowledge spillovers may be relevant at the same time is put forward by van der Panne and van Beers (2006). They find that specialized regions accommodate a higher number of innovators and, consistently, firms' innovativeness increases with regional specialization. But after the market introduction of a product the innovators in a diversified surrounding prove to be more economically successful. The writers conclude that at different stages in new product development there is room for both types of knowledge spillovers.

The debate on the two types of knowledge spillovers shows that learning depends on the external technological environment of the firm. But at the same time the internal firm capabilities do have a major impact on learning from knowledge spillovers. The exchange of knowledge does not happen automatically and some firms benefit more than others from the same opportunities. It is widely accepted that in order to recognize, understand, and economically exploit external knowledge the firm has to develop special abilities which are denoted as absorptive capacity (Rosenberg, 1974; Nelson, 1982; Cohen and Levinthal, 1989, 1990). One way to create such an absorptive capacity is for a firm to perform their own in-house research and development activities. Therefore, a firm's own R&D does not only generate innovations but develops the firm's potential to identify, assimilate, and exploit knowledge from competitors, companies of other industries, or public institutions like universities. This characteristic is marked by Cohen and Levinthal (1989) as the dual role of R&D. Hence, this argument again refers to the interpretation of knowledge as a not purely public good as firms have to bear knowledge processing and imitation costs to absorb outside knowledge and implement it in the form of product or process innovations.

The concept of absorptive capacity can be understood in the way that the knowledge bases of two interacting partners should not be too different in order to understand each other. In other words: The absorptive capacity sets a lower bar for the agents' knowledge heterogeneity. On the other hand, the learning effect is also reduced if a firm wants to absorb very similar knowledge. Therefore, the heterogeneity of knowledge should be *"sufficiently small to allow for understanding but sufficiently large to yield non-redundant, novel knowledge"* (Nooteboom, 2000, p. 72). The outcome of the knowledge exchange process could be described as a hump-shaped relation depending on technological proximity (Nooteboom, 1992, 2000; Wuyts et al., 2005). Although Nooteboom (2000) talks in this context of cognitive distance his concept can be well applied to our interpretation of technological proximity as we, in contrast to Knobens and Oerlemans (2006), explicitly include aspects of cognitive proximity in the term technological proximity.

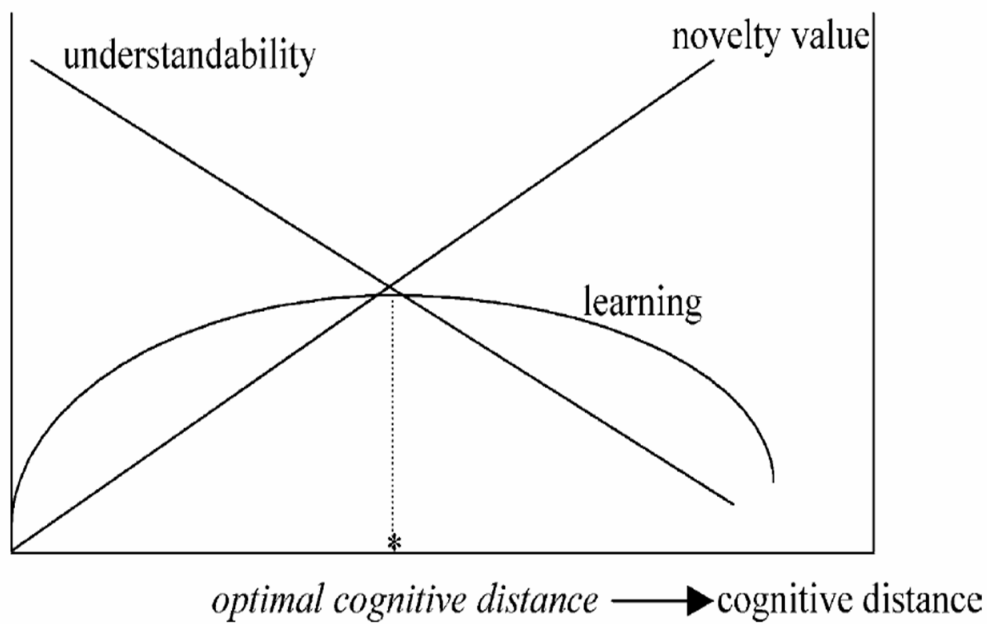


Figure 2.3: Cognitive distance and learning. Source: Wuyts et al. (2005)

Figure 2.3 visualizes the relationship between cognitive respectively technological distance and learning. The effectiveness of learning is seen as the product of novelty value and understandability. Learning is maximized for a medium level of cognitive distance, which is denoted as optimal cognitive distance. This means that firms need partners with a similar and complementary but not identical knowledge base. Learning presupposes differences of perception, interpretation and knowledge but at the same time also the existence of certain common concepts and procedures to maintain an effective linkage between partners (Nooteboom, 1992). A change of the absorptive capacity of a firm entails a shift of the line indicating understandability, e.g. a firm with a low absorptive capacity shifts the understandability line downwards, which yields a lower optimal cognitive distance. This is in line with empirical research which finds that small and technologically not very advanced firms prefer to co-operate with sources of limited capacities like customers, suppliers and colleagues instead of universities and technological institutes, which might be better partners for greater and technologically more advanced firms (Nooteboom, 2000). Hence, it is important to point out that such optimal cognitive distance is not fixed but depends on the knowledge and capabilities of the firm, which can of course change over time. Like in the examples above finding the right collaboration partner becomes a central issue.

The existence of an optimal level of two forms of cognitive distance (technological and organizational cognitive distance²²) is empirically tested by Wuyts et al.

²²Both aspects are, in our understanding, part of technological proximity.

(2005) for two scenarios. In the first case the focus is set upon on a pharmaceutical firm's overall technological cognitive distance with its biotechnology partners. The results indicate that technological innovations are most likely to occur at intermediate levels of partner dispersion. The second case reveals some statistical influence of technological and organizational cognitive distance on alliance formation in the ICT industries during 1981-1986. Further, the studies indicate that for alliances in ICT industries organizational cognitive distance is, in contrast to the first case, more important than technological cognitive distance. The authors explain this result with the fact that in ICT industries learning is more oriented toward organization because here the technology involved is more standardized. As an overall conclusion they see empirical support for the optimal cognitive distance in both scenarios. Another empirical approach approving optimal cognitive distance is given by Nooteboom et al. (2007).

So far the literature introduced is dealing with one aspect of technological proximity which can be described as the difference of the knowledge bases of the interacting partners. Another aspect of technological proximity refers to the positioning in a technology space. Among the first papers to use a measure of technological proximity between patent classes is the work by Jaffe (1986). The author finds that R&D productivity is increased by research activities of other firms in the same area, but these technological neighbors reduce the profits of firms with low R&D investments. In a later work by Adams and Jaffe (1996) the significance of geographical and technological proximity for the flow of knowledge is supported. The measure of technological closeness is also used by Autant-Bernard (2001), who describes the technological position of regions. She finds evidence that departments in France with less affinity to their neighbors are less innovative whereas departments that are technologically close to their whole neighborhood generate more innovative output. Further, the author interprets her results to the effect that geographical and technological proximity are rather complements, both favoring knowledge spillovers between regions. Fung (2003) provides a more methodologically oriented discussion of two measures of technological proximity constructed from patent statistics. Finally, Orlando (2004) and Fischer et al. (2006) again debate the role of geographical and technological proximity for local knowledge spillovers.

In the seminal article by Jaffe (1986) it is assumed that if both firms have patented in roughly the same classes the proximity measure becomes close to one, and it is approximately zero if patenting activities are greatly different (Los and Verspagen, 2007). Instead of a weight term it might be more consistent to assume a technological distance of zero, if knowledge belongs to the same technology. But a positioning with a technological distance close to zero appears to conflict with the argumentation from above, where a middle technological proximity of the knowledge

gaps between collaborators is understood to be optimal. Therefore, we need to differentiate both effects in the interpretation of technological proximity and take both into account for the formalization of knowledge spillover in the model. We do this and argue that the heterogeneity of knowledge can be expressed by the technological distance, measured by the path between two technologies in a technology space, and the technological gap between the knowledge stock of two firms in these technologies. Both elements are relevant for the resulting learning effect through knowledge spillover. Furthermore, in our model the technological proximity is connected to the characteristics and features of the product which are demanded by the consumers.

Accordingly, the definition of **technological proximity** incorporates three properties, namely the distance in a technology and product space as well as the level of technological overlap of the knowledge bases of two collaborating actors (see also Knoblen and Oerlemans, 2006). Therefore, the several meanings of our interpretation of technological proximity for the purpose of this work can be summarized as follows:

- Distance between technologies in a technology space
- Technological gap between knowledge stocks
- Characteristics in a product space.

The learning effect between two collaborating agents rises if distance in the technology space becomes very small and the level of technological overlap is neither too small nor too great. Learning is maximized if the distance in the technology space is equal to zero and the technological gap equals the absorptive capacity of the recipient.²³

The third characteristic aiming at product differentiation is not relevant for the learning outcome. However, the connection to the product space enables the assessment of the economic value of the firm's knowledge through the interaction on a product market. Here the economic value of the firm's own knowledge depends on the knowledge of the competitors, the preferences of the consumers and the substitutability to other product variants. The closer the products are in the product space, which is by assumption equal to the technology space, the more likely are consumers to switch to neighboring variants.

Our view of technological proximity can also be related to the discussion whether innovations emerge mainly from technology-push or demand-pull, see Schmookler (1966) and the relevant points in Section 2.1. The technology-push argument in our setting suggests that transfer of existing knowledge to new innovations happens

²³This context is captured in equation (4.10) which describes learning through knowledge spillovers.

if the technological distance in the technology space becomes very small and the knowledge stocks in the neighboring technologies take values close to the absorptive capacity of the firm. In that case there exist best conditions for internal knowledge transfer and, hence, the extension of the knowledge base of the firm, which might result in innovations. These innovations occur mostly due to internal learning and R&D building upon the existing technological expertise of the firm. They are, so to say, technology-pushed. The demand-pull argument is of course related to the interpretation of distances in the product space. Profits from innovation promise to be higher the more demand can be attracted to the new product - in other words the greater is the distance to the neighbors in the product space. The idea is in line with Schumpeter (1912), who states that innovators seek for profitable opportunities to earn innovative rents. A great market niche may stand for such an opportunity to combine features and introduce a product which entails the characteristics of this market segment.²⁴ In conclusion, we argue that our interpretation of technological proximity captures both elements for the creation of innovations: Either a firm's own knowledge and local search in the technology space leads to new findings, or a relatively great market niche attracts the interest of firms, which leads to intensified R&D in that area. Which elements are understood to be more significant or whether the same weight is put on both, is a matter of firm strategy. But in general both aspects have to be taken into account and, as both mechanisms often work simultaneously, it is hard to differentiate between the real origin of innovation.

Technological diversification is also closely related to market or product differentiation (Fai, 2003). The Industrial Organization literature provides a broad discussion of horizontal and vertical product differentiation (e.g. Tirole, 1988). On the one hand, products might differ in their cost or quality, whereas from a modeling point of view both aspects can be handled as the same. The differentiation in cost or quality is called vertical product differentiation. On the other hand, there is competition due to the characteristics of each product under the assumption that consumers do not prefer the same kind of products. An example of horizontal product differentiation is the range of software offered with a computer whereas the different operating speeds of personal computers might be an example of vertical product differentiation (Sutton, 1986). Hence, horizontal product differentiation comes close to our understanding of technological proximity in the product space.²⁵

Now, we should have a clearer picture of the relevant elements of innovation and the meaning of geographical as well as technological proximity. The interpretation of both - geographical and technological proximity - lies at the center of this work and

²⁴The relationship between technological distance and its connection to a product space is also highlighted by Antonelli (2004).

²⁵However, in the model we will also consider vertical product differentiation as the production costs depend on the knowledge stock in a specific technology, see Section 4.1.2.

we hope that the previous two sections have clarified our meaning. We continue with the next chapter, which discusses the availability of appropriate economic models to investigate those forms of proximity and the need for a new modeling approach.

Chapter 3

Economic Models of Innovation and Proximity

The modeling of learning through knowledge spillover depending on proximity and economic market interactions has proven to be a difficult task. Economic equilibrium models have the advantage of being fully analytically tractable whereas simulation models allow for more degrees of freedom, e.g. in the description of a geographical or technological space. This chapter introduces examples of economic models of both types, which are related to the topic of innovation and proximity. We then debate the methodology of agent-based simulation and argue why it could be appropriate in this context. Further, we argue that the cited models are not well suited to provide answers to the research questions of this work.

3.1 Analytical Models

The first model of geographical space is believed to be one of the first abstract economical models in history. It is the work by Thünen (1910) originally published in 1826. In the model he introduces the concept of land rents and their impact on the location of mostly agricultural firms around a center. The center typically represents a city and the analysis is driven by transport costs of perishable goods. Works like Christaller (1933) and Lösch (1940) show how economies of scale in connection with transport costs lead to a pattern described as central places. Another strand of literature on the geographical location of plants which already considers benefits of agglomerations was established by Weber (1909). A classical paper worth mentioning is the model by Hotelling (1929) which introduces market-based strategies in the location decision of firms. Despite the fact that d'Aspremont et al. (1979) contradict the results of the original model because they prove that the original Hotelling solution is no Nash equilibrium, the methodology and formalization of horizontal

product differentiation influenced many scholars in the field of spatial competition.¹ We will come back to this seminal paper during the description of the demand side in the model in Section 4.2.

Although many early economists considered space - at that time it was mainly geographical space - as a crucial element of economic analysis, the literature in later times almost ignored geography (Krugman, 1991b). In order to re-introduce geography back into the theoretical debate Krugman (1991b) formulated an economic model which indeed established a new strand of literature. These so called 'New Economic Geography' (NEG) models put transport cost and increasing returns into their main interest and try to explain concentration of economic activity. The basic setting of geography as core and periphery is simple but useful to disentangle agglomerating and de-agglomerating forces.² Surveys about NEG models can be found in Ottaviano and Puga (1998); Fujita et al. (2001); Fujita and Thisse (2002). Interesting is the fact, that though Krugman (1991a) mentions knowledge spillovers as a major force of agglomeration, he regarded them not to be theoretically possible to handle: "*[k]nowledge flows . . . are invisible; they leave no paper trail by which they may be measured and tracked, and there is nothing to prevent the theorist from assuming anything about them that she likes*" (Krugman, 1991a, p. 53). Authors like Jaffe et al. (1993) responded that this is not true and that knowledge flows can be measured empirically through patent citations. Martin and Sunley (1996) are convinced that the ignorance of knowledge externalities is the most important limitation of the NEG literature. Later followers of the NEG approach tried to internalize knowledge spillovers in this framework, see Martin and Ottaviano (1999); Baldwin et al. (2001). Furthermore, it has been argued that the framework of NEG assumes very specific functions, is not truly dynamic and does not catch the strategic behavior of firms, see e.g. Neary (2001). Especially the ignorance of strategic elements of the firms is criticized by Shaver and Flyer (2000). They argue that NEG models of monopolistic competition are not well suited to study strategic interactions like positioning and price competition. Further, it is debated that the NEG models discuss the location of whole industries and ignore the location decisions of single firms (Boschma and Lambooy, 1999; Stam, 2006). One can also add that most of these NEG models are not fully analytically solvable and therefore lose one of the main advantages of stylized mathematical models. Further critique of the NEG theory can be found in Martin (1999b) and Meardon (2001).

A third type of equilibrium models puts knowledge spillovers at the center of their attention. The so called 'New Endogenous Growth Theory' builds upon the neoclassical growth model of Solow (1956, 1957), in which technological progress was

¹See for example Economides (1986) for a two-dimensional version of this approach.

²This structure is also adapted in our model, see Section 4.3.3.

understood to be exogenous. The new theory tries to describe growth through technical progress generated within the model, see Romer (1986); Lucas (1988); Romer (1990); Grossman and Helpman (1991); Aghion and Howitt (1997). In particular Paul Romer stressed the importance of knowledge externalities and their role for growth. In Romer (1986) he points at the public good effect of knowledge spillovers and in Romer (1990) the flow of knowledge is captured in intermediate technology designs. Martin and Sunley (1998) criticized the approach for being overwhelmingly abstract and not incorporating aspects of geography.

A fourth class of models debates the effect of knowledge spillovers in game-theoretic models following the seminal work of Arrow (1962). DeBondt (1997) summarizes these articles from the Industrial Organization literature. More recent papers highlight the role of internal and external knowledge spillovers (Gersbach and Schmutzler, 1999), research joint ventures and knowledge spillovers (Katsoulacos and Ulph, 1998; Kamien and Zang, 2000), an interpretation of horizontally differentiated knowledge on a circular technological space (Berliant et al., 2006), and the flow of localized knowledge through the exchange of employees between competing firms (Gersbach and Schmutzler, 2003; Fosfuri and Rønde, 2004; Alsleben, 2005; Combes and Duranton, 2006). In order to debate the possibilities to model aspects of innovation and proximity we have a closer look at the model of Alsleben (2005).

The model proposed by Alsleben (2005) highlights the possible trade-off which could emerge in the context of knowledge externalities: Should firms co-locate and benefit from knowledge spillover or are they better off in separation? Here knowledge spillovers occur due to a very concrete mechanism in the form of mutual labor poaching. Knowledge is understood to be employed in 'key employees' (e.g. managers, engineers, scientists) and may flow between firms in geographically close location. Another assumption is the fact that firms may prevent poaching by offering their workers higher wages. Therefore a firm may influence not only their own, but also the wages and fraction of moving labor of the competitors. The basic setup of the model considers Cournot competition between two firms producing a homogeneous good. In an extension the assumption of a duopoly is relaxed but results also hold in the case of a symmetrical oligopoly. Firms decide upon four strategic variables in four stages: Location, height of wages for their own labor, fraction of attracted labor from the competitor, and quantities. Solving the model leads to two possible solutions: Either both firms co-locate with full poaching or firms choose separation with zero wages and zero fraction of attracted labor. In contrast to Combes and Duranton (2006), who consider a similar model with Bertrand competition, in the model by Alsleben (2005) firms never co-locate with partial poaching. The model is extended to the effect that firms differ in their ability to absorb knowledge spillovers. As a result the low-quality firm wants to join the high-quality firm but not vice versa.

If both firms choose their location simultaneously, only equilibria in mixed strategies can be calculated.

The model by Alsleben (2005) is a good example of the description of the proximity and strategic behavior of firms in a stylized game-theoretic model. The result that firms always prefer isolation unless they swap their entire personnel is interesting, since it indicates possible disadvantages of knowledge spillovers. But we would like to argue that some assumptions of this approach are very strong and that the introduction of innovation in this model would impose difficulties. First, the model describes the way of knowledge spillovers through the flow of labor. Although the mechanism is convincing, the modeling approach does not consider any labor market or specific knowledge of the workers. As formalized in the model the externality could take the form of any other cost reducing mechanism. Further, the fact that firms are able to prevent knowledge from spilling over in close geographical proximity is a rather strong assumption as argued in the previous chapter. Second, in the model the benefits of labor poaching reduce production costs in a linear form. As argued in Section 2.3 there is empirical evidence that learning takes a rather non-linear form. Third, it is not possible to retrieve a solution with heterogeneous firms. In this context this is a major disadvantage, because one of the main research question asks which type of firms agglomerate in a cluster. Fourth, the analysis is static, whereas the strategic behavior over time is probably more instructive. Fifth, the competition considers a homogeneous good although the author himself regards product differentiation as an important point in the analysis. As a last point of criticism we would like to add that no innovations are incorporated in the model. A proper description of strategic innovation behavior needs the formalization of dynamics, heterogeneity and uncertainty. Since the model already has problems describing the competition between firms which differ only in the ability to benefit from knowledge spillovers, this methodology seems to be limited for the purpose of this work. The next section introduces a different modeling approach which is probably more suitable for the formalization of innovation and proximity in an economic model.

3.2 Simulation Models

As a response to Solow (1957) another group of authors tried to endogenize the process of technological change and economic growth with the help of simulation techniques. Probably the most famous model is described in Part IV in Nelson and Winter (1982). Building on this approach there emerged a literature on growth-oriented simulation models like Silverberg and Verspagen (1994); Fagiolo and Dosi (2003); Dosi et al. (2006). The same authors also provide the seminal work for an industry model of Schumpeterian competition in Part V of Nelson and Winter

(1982) that is fundamental for our approach.³

In this section we survey all types of industry simulation models which capture aspects of innovation and proximity. A broader overview of simulation models focusing on innovation and the technological development of an industry is presented in Dawid (2006). Other surveys focus more on clusters and industrial districts (Fioretti, 2006), complexity theory (Frenken, 2006) or economic growth (Windrum, 2007).

Here we concentrate on models which describe the technological development of an industry in relation to learning in some sort of geographical or technological space. In order to group the several models we differentiate between geographical and technological proximity. All relevant models are categorized in Table 3.1. Cellular automata, cluster and networks constitute the group of geographical proximity. Learning, product space and technological regimes are related to the interpretation of technological proximity.

Further, there exist simulation models that cannot be related to a geographical or technological space. Apart from the models on economic growth (see above) authors work on topics as replication of industry empirics (Winter et al., 2000, 2003), industry life cycles (Klepper, 1996; Windrum and Birchenhall, 1998; Saviotti and Pyka, 2004; Windrum and Birchenhall, 2005), and a history-friendly approach (Malerba et al., 1999, 2001).

In the following we explain different interpretations of proximity and briefly present the methodology and outcome of selected models.

3.2.1 Simulation Models of Geographical Proximity

The simulation models which consider geographical proximity are grouped into models of cellular automata, clusters and networks. The cellular automata framework was introduced by von Neumann and Burks (1966) and became quite popular with the book by Epstein and Axtell (1996). In the models of the cellular automata framework agents interact in some sort of regular space, for example a lattice in various forms. In the models by Verspagen (1993); Caniëls (2000); Keilbach (2000) and Caniëls and Verspagen (2001) agents represent regions or countries whereas in the other models agents represent firms. In the first type regions benefit from spatially bounded knowledge spillovers whereas the intensity of spillovers depends on geographical distance between regions due to the location on the lattice. We later come back to these works because they capture aspects of learning in technological distance, too.

The latter models focus on firm behavior in a cellular automata environment.

³A more analytical approach which is based on the ideas of Nelson and Winter (1982) is presented by Iwai (1984a,b) and a different formalization to the development of routines is given in Kwasnicki and Kwasnicka (1992).

Geographical Proximity	
Cellular Automata	Verspagen (1993); Jonard and Yildizoglu (1998); Caniëls (2000); Keilbach (2000); Caniëls and Verspagen (2001); Brenner (2001); Berger (2001); Otter et al. (2001); Zhang (2003); Brenner (2004)
Cluster	Fioretti (2001); Squazzoni and Boero (2002); Albino et al. (2003); Boero et al. (2004); Fratesi (2004); Borrelli et al. (2005); Ciarli and Valente (2005); Suire et al. (2006)
Networks	Jonard and Yildizoglu (1998); Gilbert et al. (2001); Meagher and Rogers (2004); Cowan et al. (2004); Cowan and Jonard (2004); Muller and Pénin (2007)
Technological Proximity	
Learning	Verspagen (1993); Cantner and Pyka (1998a,b); Caniëls (2000); Caniëls and Verspagen (2001); Gilbert et al. (2001); Reichenstein (2003); Knott (2003); Meagher and Rogers (2004); Canals et al. (2004a,b)
Product Space	Cooper (2000); Silverberg and Verspagen (2003); Ma and Nakamori (2005); Silverberg and Verspagen (2005, 2007)
Technological Regimes	Winter (1984); Dosi et al. (1995); Meyer et al. (1996); Wakeley (1998); Llerena and Oltra (2002); Garavaglia et al. (2006)

Table 3.1: Simulation models of innovation and proximity.

Jonard and Yildizoglu (1998) and Zhang (2003) introduce extensions of the traditional Nelson and Winter (1982) model with a technological space and spatially bounded knowledge externalities. Hereby, Jonard and Yildizoglu (1998) may also be understood as a network and is discussed at a later point. Zhang (2003) studies the formation of high-tech industrial clusters in a two-dimensional geographical space. Otter et al. (2001) model the interaction between households and firms in the context of regional economics.

Two works in that category are of particular interest as they use real world data in order to evaluate the simulation model. The article by Berger (2001) develops a agent-based simulation of innovation diffusion in the context of agriculture economics. The model is calibrated with an empirical data set from Chile. The results of Berger (2001) include a replication of the typical diffusion patterns and real world prices and quantities. Further, several policy scenarios are examined with the help of the model. The second model is proposed by Brenner (2004) and is based on earlier work by Brenner (2001). The book by Brenner (2004) tries to find answers to the questions why local industrial cluster exist, when and where they emerge, and how they can be characterized. The author highlights the role of local self-augmenting processes. Apart from an empirical investigation of clusters in Germany a dynamic simulation model is formulated which incorporates spin-offs, accumulation of human capital, and knowledge spillovers decreasing in spatial distance. Geographical space is represented by the administrative districts of Germany. Those districts are sorted on a two-dimensional lattice in accordance with their calculated center of gravity. The major results indicate that the considered self-augmenting processes are together able to cause clusters but this process is not deterministic. Further, it is shown that the early times of emergence have a strong impact on the development of clusters.

The second types of simulation models in connection with geographical proximity analyze interactions within existing clusters.⁴ Most of the articles are based on the concept of industrial district, see also Section 2.2. For example Borrelli et al. (2005) investigate the performance of the industrial district in relation to different scenarios. Different types of firms interact on a grid similar to cellular automata models, but in this case the grid stands for communication and information processing mechanisms inside the industrial district. The observation of the model outcome shows that cooperative districts do not always perform best, which is, as the authors note, a widespread opinion in the industrial district literature. In particular a turbulent market demand generates best results in an industrial district in which cooperation and competition are balanced. The main disadvantage of the models in this category is the fact that by assumption firms cannot decide whether to be part of the cluster

⁴See Bischi et al. (2003) for an analytical model of two clusters.

or not. Hence, the models neglect strategic firm behavior in the context of spatial and technological location.

The third group of models of a geographical space relies on networks. Although the interpretation of a network is more based on organizational proximity, one can find arguments in favor of its connection to geographical proximity. As elaborated in Section 2.2 the interpretation of geographical proximity incorporates temporary face-to-face contacts or even general openness toward knowledge exchange with other firms and institutions. Both can be achieved with partners who can be sorted in a type of network. Hence, we see networks as one way to organize knowledge exchange in close geographical proximity.

Jonard and Yildizoglu (1998) introduce localized learning in a network into the traditional model by Nelson and Winter (1982). The network is interpreted as a two-dimensional closed lattice, which again borrows from the cellular automata approach, see above. The authors study the persistence of technological diversity which in their model is higher in a situation with an intermediate level of localization. This leads to the conclusion that there is no obvious increasing or decreasing relationship between localized learning and diversity.

Gilbert et al. (2001) describe the interaction of agents with a specified knowledge base in an innovation network, thus providing another example of a simulation model of this category. The article uses very sophisticated types of knowledge stocks and labels them as *kenes*. In their view a *kene* is given through the triple of technological capabilities, the agent's ability, and expertise level in different technological fields. The firms undergo research activities modifying and improving their *kenes* in order to discover the technology space and benefit from innovations. Thus, the model does not consider market interactions, rather there is a financial reward system for successful innovations. Research strategies of the agents include collaborations in networks where they can modify their *kenes* by exchanging knowledge with cooperation partners. Aspects of learning through technological proximity and absorptive capacity are captured in the number of overlapping capabilities. The minimum amount of overlapping capabilities needed for learning is studied in several scenarios. Furthermore, the authors apply their simulation model to different case studies and discuss policy relevant issues like the role of policy as an integrating actor in networks. Apart from the network structure the model is also mentioned in learning in the group of technological proximity.

In Meagher and Rogers (2004) the authors debate the influence of structure and function of a network on knowledge spillovers. The network is modeled as a cellular automaton but here the categorization is based on the interpretation of space which is in line with the purpose of the article. In this article the authors make use of a similar interpretation of closeness between firms, which depends on

the relative position of firms on the network. Apart from the interpretation of geographical proximity later in the article this closeness is seen as distance in a technology space. Because of this the model is mentioned in the section dealing with learning in technological proximity, too. The results show that there is a complex relationship between spillovers and aggregate innovation as well as an influence of network density on the overall outcome for innovation.

The models of Cowan and Jonard (2004) and Cowan et al. (2004) consider a network structure where all agents are located on a circle. Each agent may possess connections to direct neighbors or to more distant partners. In Cowan and Jonard (2004) the focus is set on diffusion of knowledge and informal knowledge trading between actors on the network. The authors find that best diffusion⁵ occurs in a network where most of the connections are local, supported by few global connections. The later model by Cowan et al. (2004) gives evidence that spatial clustering favors growth of knowledge in industries where tacit knowledge is important. Further, the simulations by Muller and Pénin (2007) indicate that there might exist a rationale for behaviors of open knowledge disclosures as such strategies might be risky in the short run but may pay out in the long run.⁶

3.2.2 Simulation Models of Technological Proximity

Simulation models with features of technological proximity can be divided into learning, product space and technological regimes. We go through the three types of models and then discuss why there might be need for an additional model which combines geographical and technological proximity.

The first type of models formalize learning depending on distance between two technologies or on the technological gap which stands for the difference of knowledge stocks. These knowledge stocks belong either to the same technology or to different technologies. In the latter case one can combine technological distance and technological gap in order to describe knowledge transfer between agents, see Section 2.3.

A good example of models which look at spillovers in relation to the knowledge gap are the models by Verspagen (1993); Caniëls (2000); Caniëls and Verspagen (2001). As mentioned above the agents stand for regions and knowledge diffuses through knowledge spillovers which are modeled as a hump-shaped function of the technology gap between two regions. In contrast to Verspagen (1993) the model of Caniëls (2000) and Caniëls and Verspagen (2001) allows spillovers to occur in both directions - from the technological leading agent to the backward agent and

⁵See Silverberg et al. (1988) for another simulation model on diffusion.

⁶See also the interpretation of network and geographical proximity in this work presented in Section 2.2.

vice versa. Although the first amount is larger, it is assumed that both benefit through spillovers of complementary knowledge. In all models the level of knowledge spillovers is highest if the technological gap equals a parameter which is interpreted as the absorptive capacity.⁷

Other approaches adapt the formal description of knowledge spillovers by Verspagen (1993) and build an industry dynamic model with heterogeneous knowledge spillover. Here interactions of agents on product market are modeled while focusing either on the absorptive capacity of firms in Cantner and Pyka (1998a) or the selection process with different technologies in Cantner and Pyka (1998b). Especially in the first article the authors extend the idea of absorptive capacity and find that building up absorptive capacity is a superior strategy in technologically heterogeneous environments.

Reichenstein (2003) extends the Nelson and Winter (1982) framework and modifies the imitation outcome. The author alters the imitation process to the effect that productivity increases through imitation depending on the technology gap to the best-practice of the industry. The resulting productivity is a concave function of the imitation efforts and approaches the maximum productivity of the previous period. Hence, the higher the technology gap, the higher is the amount of learning. This conflicts with the previous models following Verspagen (1993) which assume a hump-shaped relation.

A simulation model about heterogeneity and innovation in the context of firm strategy is introduced by Knott (2003). The heterogeneity of firms comes in the form of knowledge stocks, physical and technological location. The knowledge stocks can change over time, but their locations are fixed. The use of a geographical space is due to the modeling of diffusion and the technological space is needed for learning between firms sharing a common knowledge base. The shorter the geographical and technological distance the more effectively knowledge is transferred. The locations, each in one dimension, of the firms are chosen randomly from an uniform distribution and stay constant over the simulated time horizon. The amount of learning in this model increases with the difference of the knowledge stocks. The evaluation of the model leads to the insights that heterogeneity fuels growth, and that learning through spillovers does not annihilate heterogeneity if firms invest efforts to preserve their resource advantages. In conclusion, the interpretation of a geographical and technological space by Knott (2003) is very appealing and already captures the main arguments of this book, but the modeling of learning does not appear to be satisfactory because one could subsume both forms of distances into one. In the current form of the model nothing will change if both distances would represent a two-dimensional technological space. Thus, the structural differences have to be

⁷Our formal definition of knowledge spillovers borrows from that idea, see Section 4.1.3.

elements of a model in order to study the impact of geographical and technological proximity on innovation.

The research papers by Canals et al. (2004b,a) propose the use of simulation techniques for evaluating management strategies. Here the authors emphasize the build-up of knowledge through the processes of codification and abstraction and represent it in the so called I-Space. Each agent possesses knowledge assets which can be located in the I-Space, and their location changes over time as a function of a diffusion process. The agents may exchange their knowledge assets in whole or in parts with other agents and knowledge assets can become obsolete over time. The agents benefit from goods made with help of their knowledge assets and local interaction happens in a cellular automata framework.⁸ The agents remain at their randomly chosen location for the duration of their life within the simulation. The probability that agents learn from each other decreases in physical distance and further depends on the structure of the knowledge assets. Results of the papers include the finding that a knowledge blocking strategy is very costly and that an increasing degree of development of information and communication technologies increases the rents that firms receive from their knowledge assets. Furthermore, in Canals et al. (2004a) the model is applied to the conditions of Silicon Valley or Boston's Route 128. The outcome of this comparison in combination with an assumed development of information and communication technologies shows that such a dynamic will result in a reduction in the number of firms present in knowledge-based geographical clusters, will reduce the advantages of Silicon Valley's cultural model over those of Boston's Route 128, and less knowledge will be created by cluster firms relative to that produced by firms outside such clusters.

The interpretation of technological location in this book is equal to the location in a product space which is related to the preferences of consumers.⁹ Hence, the use of a product space in simulation models represents the second category of technological proximity. The article by Cooper (2000) has a closer look on the process of how firms tackle design problems. In Ma and Nakamori (2005) each product is composed of several design and performance parameters. Like other models of complexity it adapts features of Kauffman (1993). Please refer to Frenken (2006) for a survey and introduction to this type of models, which at the same time includes the following approach.

The simulation model by Silverberg and Verspagen (2005) introduces a complex technology space based on percolation theory, which is represented by a two-

⁸The sorting of the last two types of models in the category learning in technological proximity (and not cellular automata in geographical proximity) is due to its deep reliance on a technology space, although both models incorporate aspects of geographical proximity.

⁹Our model is based on Dawid and Reimann (2005) who use Chamberlainian love-of-variety preferences instead of an explicit product space.

dimensional lattice. The bounded horizontal dimension stands for technology niches, whereas the unbounded vertical dimension stands for technological performance. The lattice sites can take different states and move from discovered to viable when there exists a contiguous path of discovered or viable sites connecting it to the baseline. The lattice is discovered through local search, which sometimes results in a high number of related innovations. The model outcome is further examined upon its empirical evidence and is able to reproduce important stylized facts about the clustering of innovations in time and space, see Silverberg and Verspagen (2003). Silverberg and Verspagen (2007) introduces endogenous R&D search into this model. Firms are able to change their location in the technology space and economic competition between firms is introduced. But instead of interactions on markets firms earn profits from innovation payoffs and the payoffs are proportional to the number of levels that the frontier has moved upward by a successful innovation.

The seminal model to technological regimes, which represents the third category of technological proximity, is provided by Winter (1984). Here the author proposes to model and to discuss two stylized technological regimes.¹⁰ Following Nelson and Winter (1982) a technological regime is the technological environment of an industry under which firms operate. Hence, aspects of technological proximity appear in the form of the kind of technology space and learning opportunities of the industry.

In a model by Dosi et al. (1995) the evolution of an industry is observed under different scenarios described by several features of technological regimes. Apart from the learning conditions, which are defined as stylized archetypes called Schumpeter Mark I and Schumpeter Mark II (and an intermediate regime), the model considers birth and death of firms as well as life cycle patterns on the demand side. The model is used to explain characteristics of industrial structures by alternative regime parameters. The authors conclude that it is possible to reproduce a rich set of stylized facts. One drawback of the paper could be seen in the fact that the focus is more on showing correlations between aggregated properties and system parameters than on formulating behavior assumptions, which could be seen as major causes of the emerging regularities.

Another work by Llerena and Oltra (2002) concentrates on the aspect of learning and the diversity of innovation strategies in an industrial dynamics setup. One learning strategy is understood as internal learning-by-searching of cumulative firms. Contrary to this non-cumulative firms adopt an external learning strategy that aims at absorbing external sources of knowledge. Apart from configurations which consider a pure cumulative respectively non-cumulative case, a third configuration describes the outcome when firms with different learning strategies interact. As a result the diversity in the last scenario shows the best technological performance.

¹⁰See Section 7.2 for more details and a comparison of the results with the outcome in this book.

Here a pattern emerges where few surviving cumulative firms with high market shares generate high spillovers to a fringe of small non-cumulative firms.

Additionally, Garavaglia et al. (2006) formulate a history-friendly model of the pharmaceutical industry in which a differentiation between the two technological regimes was also taken into account. And finally, the models by Meyer et al. (1996) and Wakeley (1998) debate the influence of market structure on the innovative competition between firms, which is again related to technological regimes.

After this review of existing economic models we discuss whether any of the mentioned approaches is suitable to answer our research questions. The next section points out that in our view this is not the case.

3.3 Why another Model of Innovation and Proximity?

The model studied in the following chapters tries to combine elements of the previously addressed works and is formulated as an agent-based simulation model. In this section we would like to put forward the argument why we choose this methodology and what are crucial elements for modeling innovation and proximity. We are convinced that the method of agent-based simulation offers great possibilities to study the process of technological change with strategic behavior in a geographical and technological space. As these features are not found to our satisfaction in any existing economic model, we propose the definition of a new model. Notwithstanding, our approach rests of course on experiences and insights of former models of all types discussed.

We start by asking why an analytical equilibrium framework might not be suited to capture relevant features of innovation and proximity. We already addressed this issue when we discussed the example of a game-theoretic model by Alsleben (2005) in Section 3.1. We criticize that the assumptions concerning structure and transfer of knowledge are very restrictive, firms are not heterogeneous, the analysis is static, and that no innovations are incorporated in the model. These shortcomings of the model are typical problems when including innovation and technological change in a standard equilibrium framework. The points are also in line with Dawid (2006), where the author highlights major properties of innovation. According to him a model of innovation and technological change should consider four features: Dynamics, nature of knowledge, uncertainty, and heterogeneity.

First, after the influential work by Schumpeter (1912) it became clear that innovations are very much related to a dynamic framework. Innovations and technological change do not only distort the actual situation on a market, at the same

time they have a major impact on the further evolution of the industry structure. The incumbents are threatened by new innovators and have to innovate themselves in order to stay competitive. On the other hand, established large firms benefit from new products and better processes and try to extend their market position, see Schumpeter (1942). Second, knowledge is a precondition for successful innovations and, as Dosi (1988a,b) shows, it can only be gained through a cumulative activity. Firms can learn through internal research or external knowledge spillovers but in every case the outcome depends on the knowledge already accumulated in the firm. The tacitness of knowledge is also crucial for the transfer of knowledge between agents. At this point proximity comes into play, but this is discussed in detail in Chapter 2. The third argument highlights the immanent uncertainty of innovations. An economic agent cannot predict the technological development and will never be sure if and when the firm's own investments in R&D lead to a breakthrough. Furthermore, agents do not know about the concrete type of a breakthrough - e.g. incremental or radical. In order to handle this uncertainty agents adapt a behavior based on routines (Nelson and Winter, 1982).¹¹ And fourth, the analysis of learning and innovation cannot leave out heterogeneity between agents. Firms can only learn from each other if knowledge is sufficiently different. Heterogeneity is crucial not only for the process but for the result of innovations: *"The whole point of innovating for firms is to distinguish themselves from the competitors in the market according to production technique or product range, thereby generating heterogeneities."* (Dawid, 2006, p. 1240). Thus, innovation demands heterogeneous firms, technologies and products and without heterogeneity it is not possible to understand competition and economic performance (Jensen and McGuckin, 1997). Apart from the four major concerns we would like to add an endogenously changing industry structure as a further important feature of an innovative industry (e.g. in the form of industry life cycles, see Klepper, 1996).

Summing up, to understand the process of innovation and technological change we need a dynamic framework in which heterogeneous agents interact in a complex environment. The complex environment should contain relevant market and non-market interactions like learning through knowledge spillover depending on geographical and technological proximity. Apparently, the outcome of non-market interactions must have a link to the economic markets in order to close the model. Therefore, the proposed elements make it hard to investigate issues of innovation and technological change with the standard methods of equilibrium analysis. One way to meet this challenge comes with the methodology of agent-based simulations.

According to Tesfatsion (2006) an agent-based simulation model allows *"a computational study of economic processes modeled as dynamic systems of interacting*

¹¹See Rosenberg (1994) for a critique of the evolutionary approach and routines especially.

agents” (Tsfatsion, 2006, p. 835). Apart from the interactions between autonomous decision-making agents this framework allows an investigation of emerging properties of the system.¹² The emergent properties arise due to the goal-oriented or unintended behavior of the individuals in the model. The model includes a definition of data and behavioral methods for agents as well as an initial state of the economic system. Like a computational laboratory the analysis is based on observations of the system over time without any interventions from the modeler. Several repetitions of one or more scenarios allow a statistical analysis of the model outcome. The structure and findings of the model have to be written down in such detail that a third person can implement the model and reproduce the proposed results. Critical issues in this field are verification and validation of simulations, which are discussed in greater length in Chapter 5.

Four main objectives of the researcher in agent-based computational economics are distinguished by Tsfatsion (2006): Empirical understanding, normative understanding, qualitative insight and theory generation, and methodological advancement. Similarly, Bruun (2004) proposes three different justifications for agent-based simulation models in economics: First, the reproduction of theoretical results of analytically tractable models. Second, to reproduce previously not formalized theory or to investigate issues that cannot be solved analytically. Third, to reproduce stylized facts and understand the mechanisms behind empirical findings. For further surveys of the methodology of agent-based computational economics please refer to Axelrod (2006) or Pyka and Fagiolo (2007) and to the previous section for examples of agent-based simulation models.¹³

In the context of this book agents are heterogeneous firms and consumers with heterogeneous preferences in an evolving industry. Emergent properties here are the formation of clusters in a geographical space and the overall technological development of an industry which is driven by agents’ search and learning activities. We define the behavior of firms with the help of routines embedded in their institutional framework and market interactions are represented as a single period equilibrium system in the tradition of evolutionary modeling (Nelson and Winter, 1982). The main objective of this approach concentrates on theory generation complemented by a normative analysis of selected issues.¹⁴ As already addressed, the theory behind innovation and proximity demands modeling features that are difficult to assess in analytical models. Therefore, we implement our interpretation of innovation and

¹²This characteristic is captured best in the title of the book by Schelling (1978): *Micromotives and Macrobehavior*.

¹³See also the extensive on-line resources at <http://www.econ.iastate.edu/tesfatsi/ace.htm>.

¹⁴The evaluation of regional innovation policies in Section 7.3 is an example of a normative discussion.

proximity in an agent-based simulation model to achieve a quantitative analysis which cannot be provided by an analytically solvable model. Furthermore, our findings are compared to empirical work in order to compare our results with reality. Part III of this book shows examples of several scenarios which differ in their initial conditions, economic environment, types and number of agents, and the possibilities of the agents.

After collecting arguments for the methodology the remainder of this section debates the question why previous agent-based simulation models do not capture all relevant aspects of innovation and proximity. We see four major features the model has to consider in order to investigate the topic of the book: Endogenous choice of location, both geographical and technological distance in one model, structural differences between these forms of proximity, and economic interactions on markets.

The first point captures the fact that in many models location is chosen randomly and firms cannot alter their position strategically. Firms should have the possibility to influence their position in space which must have an influence on the outcome on the product market. For example the models of clusters do in general not model firms leaving the cluster and elsewhere location is often kept fixed (see e.g. Verspagen, 1993; Knott, 2003; Canals et al., 2004a,b). Second, as argued in Chapter 2 at least two forms of proximity are necessary to get the main idea behind knowledge spillovers: Geographical and technological proximity. Hence, both forms are to be integrated at the same time but earlier models do not consider this (e.g. Cantner and Pyka, 1998a,b; Silverberg and Verspagen, 2005). Third, the interpretation of geographical and technological distance and its influence on innovation bears structural differences. Especially, the nonlinear relationship between learning in technological distance needs to be included. Considering one type of proximity, which can be interpreted either as geographical or as technological proximity, is not satisfactory (e.g. Knott, 2003; Meagher and Rogers, 2004). And finally, the economic success of firm strategies and technological breakthroughs can only be quantified by competition in a market. The economic value of a firm's knowledge assets always depends on the assets of the competitors and the preferences of the consumers. Enjoying a small fraction of knowledge in an isolated technological area may lead to higher profits than having a large amount of knowledge in a popular technology where many competitors possess distinct knowledge, too. The same holds for innovations which do not meet the needs of consumers. From the point of view of a firm there is a difference between knowledge and economic valuable knowledge. Therefore, the economic value of knowledge can only be specified by market interactions. Previous models of innovation and proximity sometimes lack this economic foundation (e.g. Gilbert et al., 2001; Knott, 2003).

If a model aims to address the issue of innovation and proximity, these features have to be considered at the same time. At least to our knowledge this has not been done so far, which justifies the formulation of a new agent-based simulation model. As the need for a new model of innovation and proximity becomes evident, we introduce our attempt to fill the research gap in the forthcoming chapter.

Part II

The Model

Chapter 4

An Agent-Based Simulation Model of Innovation and Proximity

This chapter introduces the agent-based simulation model which is analyzed and extended in the following part of this work. The simplest version of the model represents the evolution of a dynamic and innovative industry inhabited by heterogeneous firms and consumers. The main focus is set on the technological development in terms of process and product innovations, aspects of learning depending on proximity and the strategic behavior of firms that are direct competitors on related product markets. The model allows the description of an endogenously evolving technology space, which is driven by the innovation behavior of firms. The technological space is connected to the product space which determines the demand of the consumers depending on the number and scope of product variants. Further, the dynamics of firm location in geographical and technological space as well as the market structure result endogenously from the interactions between firms and consumers.

The major trade-off for the strategic behavior of the firms lies in the evaluation of possible positive learning effects versus the possible loss of economic valuable knowledge in close geographical proximity. Another important aspect of strategy could be seen in the way firms develop their technological portfolio over time whereas the technological portfolio stands for the amount and area of knowledge in the technology space. The model enables a complex and dynamic determination of economic profits through the interaction on differentiated product markets which depends on the preferences of the consumers as well as the knowledge and behavior of the firm and its competitors.

As pointed out before, a precondition for the evaluation of innovation is a dynamic setting. The method of agent-based simulations can provide a very simple dynamic representation as repetition of agent interaction is the basis of this concept. In order to debate learning, firm strategy and innovation the assumption of

heterogeneity is crucial as well: Learning through knowledge spillover can only occur between agents who do not have the same knowledge. One can only evaluate firm strategies if the behavior of firms differs within or between scenarios, for example the choice for a geographical and technological location of the company. And finally as investments in R&D are connected to uncertainty in the outcome (see e.g. Dosi, 1988a), firms have to differ in their innovation results even if research strategy and the amount of investments are constant. Therefore this model is largely based on heterogeneity, which can be adequately modeled with the help of agent-based simulation.¹

To be very clear, this model does not examine other agglomeration or de-agglomeration forces than learning through knowledge spillover between competitors on horizontally related product markets. For example Marshall (1920) mentions (apart from knowledge spillovers) labor market pooling or the benefits of specialized input factors (see also Porter, 1998). Negative effects of accumulation of economic activity like increasing land rents, congestion or pollution are not included in the model either.² All forthcoming propositions, firm strategy and policy recommendations do only rely on the isolated effect of knowledge externalities described in the model and should never be understood as general advice. The chosen assumptions and parameter settings limit the scope of the recommendations, too. The assumed formal description is introduced in this chapter and the discussion of the parameter settings follows in Chapter 5.

The model is based on previous work by Dawid and Reimann (2005, 2007). Building on their framework of an innovative industry Wersching (2007a) introduces aspects of technological and geographical proximity in this setting. In contrast to the version of this book the model of Wersching (2007a) relies on an interpretation of a representative consumer and another major difference is the usage of congestion cost for highly populated firm agglomerations. The paper by Dawid and Wersching (2006) uses the same model in order to have a closer look on firm strategies. In Wersching (2006) the demand side and firm strategies are changed but it is still a preliminary version of the setup introduced here. All major topics of the previous articles are again taken up in this book in a consistent and unified framework with a more elaborated version of the simulation model in the applications Part III. In general the model was built and modified such that our research questions can be addressed with a formalization which is as simple as possible. Still, the model setup is quite complex, but later on in the applications part it will become evident why this complexity is needed for debating the main issues of this book.

Before going into details of the model the time-line of each simulated period

¹See also the argumentation in Section 3.3.

²For possible extensions of the standard model please refer to Chapter 8.

is shown. These events are repeated over T periods and provide the basis of the programming code in MATLAB:

1. The environment of the industry changes:
 - Bankrupt firms are exchanged.
 - Knowledge of the firms increases through investments in R&D and through knowledge spillovers.
 - Product innovations occur leading to the generation of new sub-markets.
2. Consumers choose a sub-market.
3. Firms make decisions:
 - Firms evaluate all existing sub-markets.
 - Firms decide on market exit and market entry.
 - Output quantity decisions are made.
4. Market clearing prices are calculated and profits are realized.
5. Firms choose the focus and height of investments:
 - Investments in the geographical location.
 - Investments in product and process innovations.
6. Savings of the firms are calculated.

The details of the model and the realization in the agent-based simulation model are introduced in the following sections, which present the technological environment, the behavior of firms and consumers as well as the calculation of the single-period equilibrium system as it was called by Nelson and Winter (1982).

4.1 The Technological Environment

The technological environment determines the knowledge formation, the representation of learning through knowledge spillovers and the demand conditions of our artificial industry. We start with the introduction of the technology space.

4.1.1 The Technology Space

The technology space is interpreted as a circle in the tradition of the circular city models in the Industrial Organization literature (see e.g. Schmalensee, 1978; Salop, 1979) which build on the seminal work of horizontal product differentiation by Hotelling (1929). Other models like Jonard and Yildizoglu (1998) and Keilbach (2000) formulate the technology space as a torus, but for the purpose of this work a circle seems to be a useful solution, because it enables the calculation of technological specialization as will be seen in Section 6.1. The idea is that products belonging to a technology j , which marks a certain point on that circle, are horizontally differentiated.³ To keep things simple it is assumed that product differentiation is entirely due to technological differences between products and hence product positioning is equivalent to technological positioning.

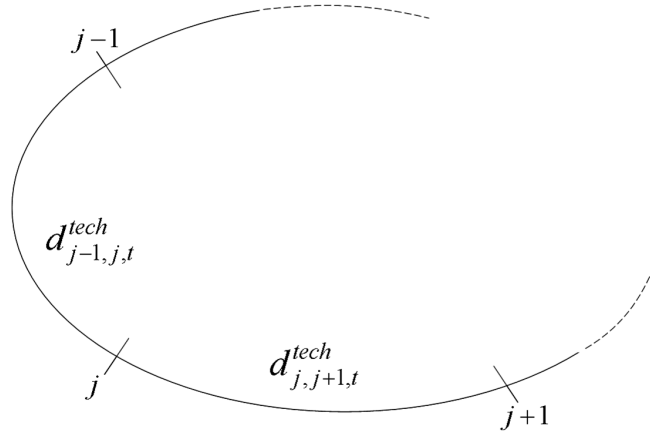


Figure 4.1: The technology space as a circle.

The technological distance $d_{j,j+1,t}^{tech}$ between two technologies j and $j + 1$ is interpreted as the shortest path on the circle in period t . The technological distance can be interpreted as a market niche, because the bigger the technological distance between two markets the more customers are attracted to the neighboring product variants, see Section 4.2 for more details. The technological interpretation builds on the level of similarity of related technologies: The closer two technologies are the easier is the transfer of knowledge. The overall number of existing technologies should be m_t . In figure 4.1 the technological space and the corresponding technological distances are shown.

A successful product innovation adds a new technology on the circular technology space. Here the interpretation of product innovations is based on the term of a niche innovation introduced by Abernathy and Clark (1985). The new technology creates

³Sutton (1998) discusses a similar interpretation of product differentiation under the heading of the independent sub-markets model.

a new market opportunity but this new technology does not make obsolete the knowledge of neighboring firms.

Two forms of product innovations are implemented in the model:

1. **Incremental Product Innovation:** This type of product innovation stands for a new variant of the industry product which combines elements of neighboring technologies. The firm wants to get close to a promising technology j but while all products are substitutes, it chooses j as a neighbor but as far as possible. The firm will choose a technological location next to j where the technological distance to the next technology is greatest. Thus the incremental product innovation is a better solution for customers who are technologically distant from existing technologies, because the new market $m_t + 1$ emerges right in the middle between two existing ones and the technological distances change to:

$$d_{j,m_t+1,t}^{tech} = d_{m_t+1,j+1,t}^{tech} = \frac{d_{j,j+1,t-1}^{tech}}{2}.$$

In Figure 4.2 an incremental innovation is illustrated.

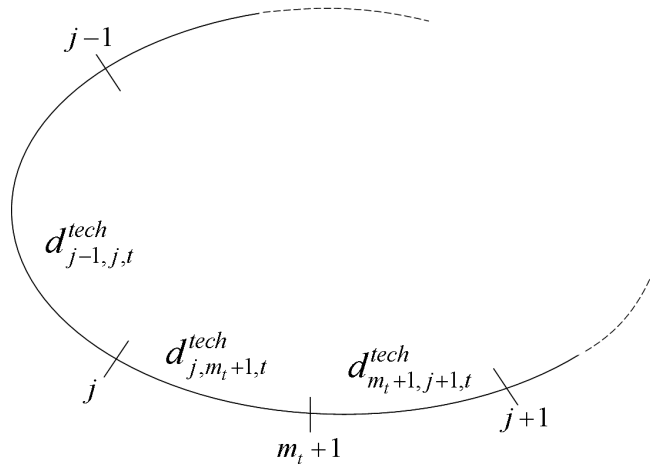


Figure 4.2: Incremental product innovation.

2. **Radical Product Innovation:** In contrast to the previous kind a radical product innovation adds significant new features to the product of the industry which go beyond a pure combination of existing product characteristics. The interpretation of a radical product innovation is not in the sense of Dosi (1982) or Freeman and Perez (1988) because here no change of paradigm is connected to the new technology. The interpretation of these authors would lead to major change like e.g. a new dimension in the technology space. Here the term radical is only used to differentiate it from the other type of product innovation. In order to represent this in the model the circumference of the technology space increases as new consumers are attracted to the industry. As in the case of an incremental product innovation the firm will always choose a location where the distance to their neighbors is greatest but in the neighborhood of a specified technology j . The circle is extended depending on the location of the new radical product innovation $m_t + 1$:

$$d_{j,m_t+1,t}^{tech} = d_{m_t+1,j+1,t}^{tech} = d_{j,j+1,t-\tau}^{tech}.$$

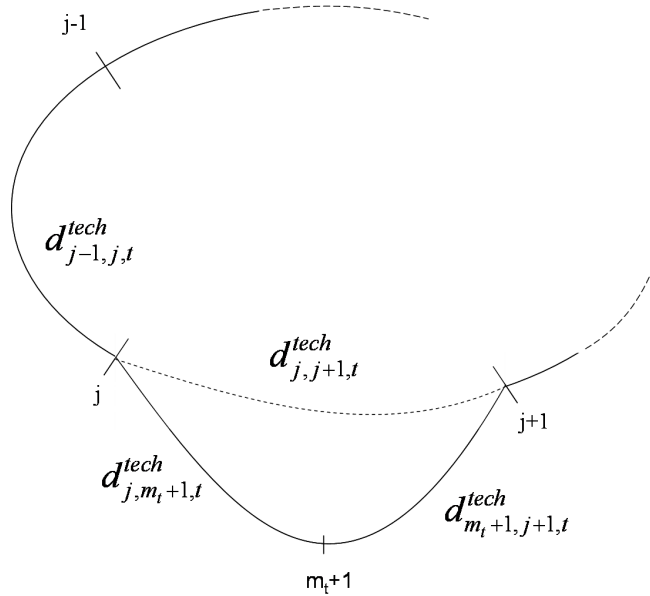


Figure 4.3: Radical product innovation.

For τ periods both connections exist, but later the connection between j and $j+1$ is only possible via the new technology $m_t + 1$. The old connection $d_{j,j+1,t}^{tech}$ is cleared after τ periods. The innovating firm with a new product stays for τ periods as a monopolist on this new market. After this period other firms may produce and sell this product variant, too. In Figure 4.3 the impact of a

radical product innovation is shown.

At this point it may be important to mention that the resulting effect for a company, e.g. profits on the new market, may be bigger in case of an incremental product innovation in a large market niche than in case of a radical product innovation in an area with very small technological distances. But for the industry the total demand in the first scenario stays constant whereas in the case of the second scenario new consumers are attracted to this industry and this effect justifies the interpretation of a radical product innovation.

An example of the technology space comes from the automobile industry: Starting with three main technologies (freight vehicles, passenger cars and buses), the introduction of vans and SUVs (sport-utility vehicles) could be interpreted as product innovations. In Figure 4.4 the example is represented. Vans are indicated as an incremental innovation which combines features of the neighboring industries (buses and passenger cars). SUVs could stand for a mixture between passenger cars and freight vehicles. The presentation of SUVs with the help of marketing instruments attracted new consumers to the automobile industry or convinced consumers to spend more money on their cars. For this, SUVs should be considered (at least in economic perspective) as a radical product innovation. The widening of the technology space leads in total to higher profits for the innovator, at least in the short run before competition was intensified as more and more automobile producers started to fabricate SUVs. A more detailed technological space could be imagined by sorting brands or design models of the automotive industry on the circle.

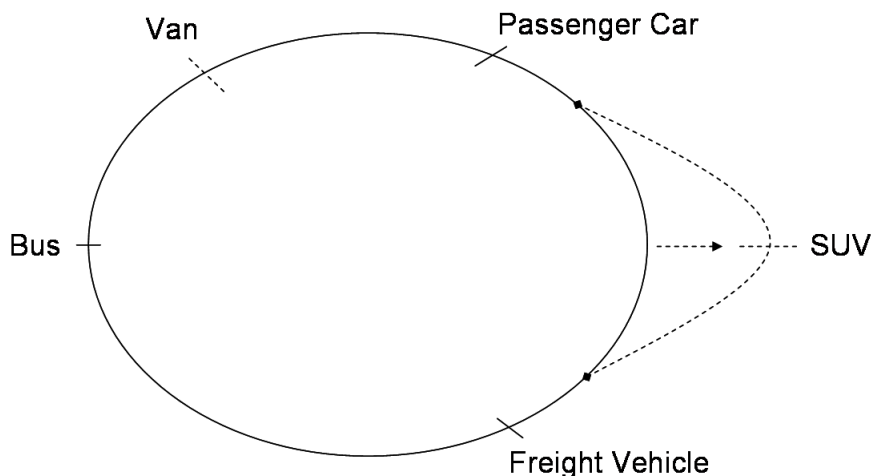


Figure 4.4: The technology space and an example from the automobile industry.

In an search model by Berliant et al. (2006) a very similar technology space and interpretation of learning was used. But the authors rely on a very broad interpretation of the points on the circular knowledge space as they stand for any fields of

relevance, such as art, biology, history, physics, and economics. In the context of this industry model one can imagine different fields of production technologies for similar products as a second example of the technology space.

4.1.2 The Role of Knowledge

The knowledge of firms is one of the most important elements of the model. Each firm holds two forms of knowledge in each technology which stand for the level of process respectively product innovation. On the one hand, the company may introduce a new method, which leads to lower production cost, or it presents a better version of an existing product. On the other hand, the firm wants to launch a brand-new product in order to meet the needs of new consumer groups or to establish a new product variant in a promising market niche. The first part of the technology profile is captured by a knowledge stock for process innovations $RD_{i,j,t}^{proc}$ and the second part by a knowledge stock for product innovations $RD_{i,j,t}^{prod}$, both depending on the company i , the technology j and the time period t .

Both stock variables can be increased either by the company's own investments in R&D ($I_{i,j,t}^{proc}$ or $I_{i,j,t}^{prod}$) or by knowledge spillover ($SP_{i,j,t}^{proc}$ or $SP_{i,j,t}^{prod}$), where investments in R&D and spillover are understood as perfect substitutes. The build-up of a knowledge stock for innovations has the property that it is a cumulative and time consuming process where experiments and knowledge are accumulated step by step over time. Further, it is assumed that the return to investment, measured by increases in the knowledge stock, decreases as the company approaches the frontier of RD_j^{max} . Knowledge starts at zero or at an initialized number in the interval $[0, RD_j^{max}]$. Afterward the knowledge stock is updated as follows:

$$RD_{i,j,t}^{proc} = RD_j^{max} - (RD_j^{max} - RD_{i,j,t-1}^{proc}) \frac{1 + \alpha_i \beta_i (I_{i,j,t-1}^{proc} + SP_{i,j,t}^{proc})}{1 + \alpha_i (I_{i,j,t-1}^{proc} + SP_{i,j,t}^{proc})} \quad (4.1)$$

Here $\alpha_i > 0$ and $\beta_i > 0$ are firm-specific parameters which describe the ability of the firm to develop new products and the efficiency of the use of R&D funds. In particular, firm i can in each period reduce the gap to the frontier RD_j^{max} at most by the factor β_i . Equation (4.1) also represents the cumulative property of knowledge. In the standard scenario the upper border of the technology stock is set to $RD_j^{max} = 1$.

Figure 4.5 shows an example of the functional form of equation 4.1 with different firm parameters $\alpha_1 < \alpha_2$ and β . With given RD_{t-1}^{proc} the maximum level of process innovation, which can be reached for $(I^{proc} + SP^{proc}) \rightarrow \infty$, is given by: $RD_j^{max} - \beta \cdot (RD_j^{max} - RD_{t-1}^{proc})$. Thus the parameter β influences the maximum value. The parameter α governs the gradient of the curve. A firm with better capabilities to

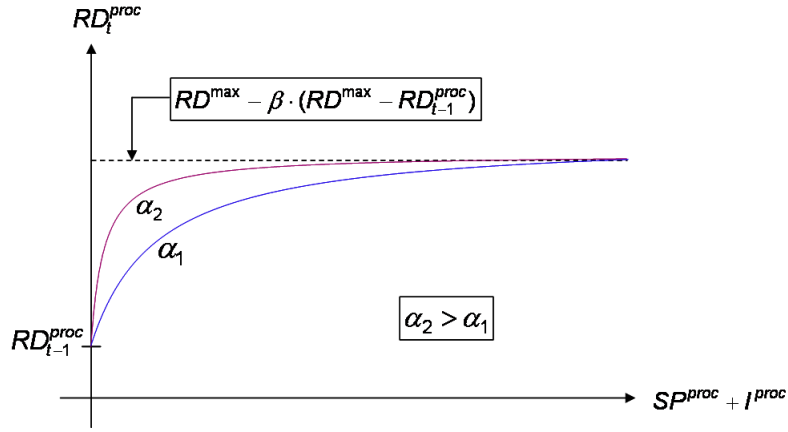


Figure 4.5: The function for the knowledge of process innovations.

perform R&D (higher α and β) can increase its level of process innovations much higher and faster with the same amount of investments and knowledge spillovers than a firm with lower parameter values.

The level of knowledge for process innovations for each technology corresponds with the production cost $c_{i,j,t}$ for variant j of firm i in t . A rising knowledge stock for process innovations $RD_{i,j,t}^{proc}$ leads directly to lower production cost. The variable production costs $c_{i,j,t}$ depending on the corresponding knowledge stock $RD_{i,j,t}^{proc}$ are formulated in the following way:

$$c_{i,j,t} = c^{ini} [c^{min} + (1 - c^{min})(1 - RD_{i,j,t}^{proc})] \quad (4.2)$$

The parameters c^{ini} and c^{min} are constant over time and do not depend on firm i . Heterogeneities in production cost result only from the differences in the firms' knowledge stock $RD_{i,j,t}^{proc}$. The variable costs start at c^{ini} with no specific knowledge in this technology ($RD_{i,j,t}^{proc} = 0$) and the cost can be diminished up to $c^{ini} \cdot c^{min}$ for the highest knowledge values ($RD_{i,j,t}^{proc} = 1$). Altogether firms have the following cost structure with given output quantities $x_{i,j,t}$:

$$C_{i,t}(x_{i,j,t}) = F_i \cdot |M_{i,t}| + \sum_{j \in M_{i,t}} (c_{i,j,t} \cdot x_{i,j,t}^2) \quad (4.3)$$

Each of the n firms in the industry can in every period produce for each of the public sub-markets. $M_{i,t}$ is the set of markets the firm i produces for in period t and $x_{i,j,t}$ is the output quantity of firm i on sub-market j . The fixed costs F_i are a constant firm-specific parameter. For every sub-market the firm produces for, fix cost F_i rise.

The equation for updating the knowledge stock for product innovations can be

formulated analogously to (4.1) with the fixed upper border of 1:

$$RD_{i,j,t}^{prod} = 1 - \left(1 - RD_{i,j,t-1}^{prod}\right) \frac{1 + \alpha_i \beta_i (I_{i,j,t-1}^{prod} + SP_{i,j,t}^{prod})}{1 + \alpha_i (I_{i,j,t-1}^{prod} + SP_{i,j,t}^{prod})} \quad (4.4)$$

In contrast to process innovation a knowledge stock for product innovation greater than zero does not automatically lead to successful product innovation. In fact the immanent uncertainty with product innovations is captured by a stochastic process which determines whether a product innovation is successful or not. A product innovation can be either incremental or radical. Two numbers were chosen: u from the uniformly distributed interval $[c, d]$ with $0 < c < d$, and v from the uniformly distributed interval $[d, e]$ with $d < e \leq 1$. If $RD_{i,j,t}^{prod} > u$ the firm i was able to introduce a product innovation on the market. If $RD_{i,j,t}^{prod} > v$ the new product was a technological breakthrough, which could be interpreted as a radical innovation. Otherwise the product innovation is incremental.

Therefore, the probabilities for a successful incremental product innovation $P_{inc}(RD_{i,j,t}^{prod})$ and for a radical product innovation $P_{rad}(RD_{i,j,t}^{prod})$ depending on the current knowledge stock for product innovations $RD_{i,j,t}^{prod}$ can be written as:

$$P_{inc}(RD_{i,j,t}^{prod}) = \begin{cases} 0, & \text{for } RD_{i,j,t}^{prod} < c; \\ \frac{RD_{i,j,t}^{prod} - c}{d - c}, & \text{for } c \leq RD_{i,j,t}^{prod} < d; \\ 1 - P_{rad}(RD_{i,j,t}^{prod}) = \frac{e - RD_{i,j,t}^{prod}}{e - d}, & \text{for } d \leq RD_{i,j,t}^{prod} < e. \end{cases} \quad (4.5)$$

$$P_{rad}(RD_{i,j,t}^{prod}) = \begin{cases} 0, & \text{for } RD_{i,j,t}^{prod} < d; \\ \frac{RD_{i,j,t}^{prod} - d}{e - d}, & \text{for } d \leq RD_{i,j,t}^{prod} < e; \\ 1, & \text{for } e \leq RD_{i,j,t}^{prod} \leq 1. \end{cases} \quad (4.6)$$

The initial R&D stock for a new product variant is chosen randomly from the interval $RD_j^0 = [RD^0, RD_j^{max}/2]$. After the successful introduction of a new product variant the knowledge stock in this particular field is erased ($RD_{i,j,t}^{prod} = 0$).

4.1.3 Proximity and Learning through Knowledge Spillovers

So far the technological aspects of proximity have been shown in the model. Firms do have different knowledge stocks which can be located in the technological space. The similarity of knowledge in one particular technology and the path on the circular technology space between two technologies are part of the interpretation of the

technological proximity, see Section 2.3.

The geographical aspects of proximity and their impact on learning is captured by the geographical distance $d_{i,t}^{geo}$ of firm i . The geographical distance is modeled similar to core-periphery models in the New Economic Geographic literature (see e.g. Krugman, 1991b). There are only two possible locations for firms: At the core (or agglomeration) or outside on the periphery. A location at the core leads to a better exchange of tacit knowledge. If a company is a technological leader, it might also prefer a location on the periphery in order not to let too much knowledge spill over upon competitors, because it is assumed that firms cannot prevent knowledge from spilling over.

$$d_{i,t}^{geo} = \begin{cases} 0, & \text{at the core;} \\ 1, & \text{on the periphery.} \end{cases} \quad (4.7)$$

Heterogeneity of knowledge is a precondition for learning. The differences in knowledge are interpreted in two ways: First, there are technological distances between different strands of technologies. Second, there is a difference between two knowledge stocks which represents the knowledge gap. The knowledge gap $t_{ik,jl,t}$ between firms i and k related to different technologies j and l in period t is:

$$t_{ik,jl,t} = \max \left\{ \ln \left(\frac{RD_{k,l,t}^{proc}}{RD_{i,j,t}^{proc}} \right), 0 \right\} \quad (4.8)$$

In this formula the technological gap is only greater than zero, if the other company k has a greater value of the knowledge stock variable. Furthermore, the function is concave.

As discussed in Section 2.3 the absorptive capacity of a firm is crucial for learning through knowledge externalities. The concept of absorptive capacity is incorporated in the variable $\gamma_{i,t}$ of firm i in t , which is assumed to be the mean value over all m_t technologies. Therefore a firm with a high amount of technological knowledge is able to absorb a higher fraction of external and internal knowledge:

$$\gamma_{i,t} = \frac{\sum_j^{m_t} RD_{i,j,t}^{proc}}{m_t} \quad (4.9)$$

Now we do have all ingredients for the calculation of knowledge spillovers which represent learning in the model. Firms i and k can learn from competitors only if both of them are placed at the core, that is $(1 - d_{i,t}^{geo}) \cdot (1 - d_{k,t}^{geo}) = 1$. But learning can also happen within the firm, where knowledge is transmitted from one field to another. Learning regards all technologies m_t . Based on the formula for knowledge spillover from Verspagen (1993) and Cantner and Pyka (1998a,b)

and the argumentation in Section 2.3 with two kinds of distances $d_{i,t}^{geo}$ and $d_{j,l,t}^{tech}$, the technological gap $t_{ik,jl,t}$ and the absorptive capacity $\gamma_{i,t}$, the resulting knowledge spillover for process innovations $SP_{i,j,t}^{proc}$ for the technology j and firm i can be written as:

$$SP_{i,j,t}^{proc} = \sum_{l=1}^{m_t} \sum_{k \neq i} \left[(1 - d_{i,t}^{geo})(1 - d_{k,t}^{geo}) \cdot \frac{1}{1 + d_{j,l,t}^{tech}} \cdot t_{ik,jl,t} \cdot e^{-\frac{t_{ik,jl,t}}{\gamma_{i,t}}} \right] + \sum_{l=1}^{m_t} \left[\frac{1}{1 + d_{j,l,t}^{tech}} \cdot t_{ii,jl,t} \cdot e^{-\frac{t_{ii,jl,t}}{\gamma_{i,t}}} \right] \quad (4.10)$$

Analogously the knowledge spillovers for product innovations $SP_{i,j,t}^{prod}$ are formulated.

Similar to Gersbach and Schmutzler (1999) a differentiation between external and internal knowledge spillovers is used. The first term stands for the external knowledge spillover. It is only greater than zero if both firms are at the core. The second term stands for internal knowledge spillovers which emerge independent of the geographical location of the firm. The formula is built such that it is maximized if the technological gap equals the absorptive capacity. Any deviations from this point lead to lower knowledge transfer. This represents that learning has less effect if the knowledge is too similar or too different. A higher technological distance $d_{j,l,t}^{tech}$ between the two technologies j and l in questions reduces the possible learning effect.

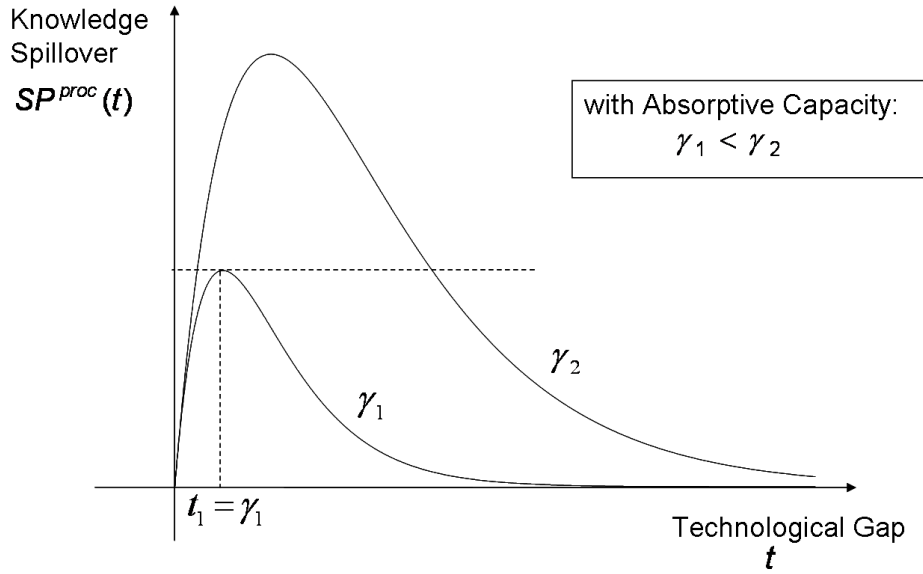


Figure 4.6: An example of the calculation of knowledge spillovers $SP^{proc}(t) = t \cdot e^{-\frac{t}{\gamma}}$ with given absorptive capacity $\gamma_1 < \gamma_2$ depending on the technological gap t .

The functional form is shown in Figure 4.6. One can see that the maximum learning effect is reached in $t = \gamma_1$ (respectively $t = \gamma_2$). A technological gap greater than that reduces the learning effect as the basis for learning gets weaker. Firms with on average more knowledge in several technologies have a greater absorptive capacity and therefore can benefit much more from learning. Therefore, the formalization of knowledge spillovers in this model takes at the same time into account the non-linear relation between technological gaps, aspects of absorptive capacity, the technological distance in a technology space and geographical proximity. It is in line with the theoretical arguments and empirical findings discussed in Chapter 2. Learning in this model is described in such a manner that the technological profiles of two firms are compared and the specific gains are calculated. Even without any own investments of their own in R&D firms could increase their specific knowledge by learning.

4.2 The Demand for Products

The consumers in the model are heterogeneous in their technological preferences. It is assumed that the consumers are continuously and uniformly distributed over the technology space.⁴ The consumers have to make two decisions: First, at the beginning of each simulation round they select the sub-market or the kind of product variant of interest and second they choose the quantity (or set the prices according to the offered quantities by the firms) of the previously selected product variant in the market clearing phase.

The selection of the sub-market builds upon the models of spatial competition (e.g. Hotelling, 1929; d'Aspremont et al., 1979; Salop, 1979) in which two factors seem of major interest: The technological distance from the location of the consumer to the location and the price of the product variant. The farther a product variant is to the location of a consumer, the lower has to be the price in order for the product variant to be selected by this consumer.

At the time of decision making the consumers do know the current status of the technology space, this means that they know all technological distances $d_{h,j,t}^{tech}$ from the consumer h to the sub-market j in the current period t . For the prices $p_{j,t}$ the situation is different, the consumers do only know the prices of the last period and

⁴Apart from a uniform distribution one can imagine several possible extensions of the model while using different distributions.

they expect them to stay constant:⁵

$$\hat{p}_{j,t} = p_{j,t-1}. \quad (4.11)$$

A consumer would prefer a product with the characteristics which are given by his own technological location. In general the industry offers only products which do not exactly match his needs, and so each consumer has to decide upon similar alternative product variants and their prices. The consumer would to a certain degree substitute a product with less favorable properties, if the price of the technologically farther product is lower. Therefore the farer away or the less interesting a product is from the perspective of an individual consumer and the higher the price, the less attractive is a product variant. The decision of the sub-market can be formulated by the following evaluation function $v_{h,j,t}^{cons}$ of the consumers h for market j in t :

$$v_{h,j,t}^{cons} = \bar{s} - d_{h,j,t}^{tech} - \hat{p}_{j,t} = \bar{s} - d_{h,j,t}^{tech} - p_{j,t-1} \quad (4.12)$$

The evaluation function of the consumer is equal to the utility function in the traditional model of horizontal product differentiation by Hotelling (1929). It is assumed that \bar{s} is high enough that every consumer picks one sub-market. The first term $d_{h,j,t}^{tech}$ expresses how well the characteristics of the product fit the prospects of the consumers and the expected price $\hat{p}_{j,t}$ completes the evaluation of the sub-market. Figure 4.7 shows the situation of a consumer who has to decide between the two neighboring product variants j and $j + 1$ with different prices $p_{j,t-1} > p_{j+1,t-1}$.

The possible location of a consumer is marked by d and it is counted from the sub-market j . The technological distance between these two alternative markets is given by $d_{j,j+1,t}^{tech}$. It is assumed that the price of $j + 1$ is lower than the one of j . Because of this, more consumers are attracted to market $j + 1$ than to market j . Depending on the preferences of the consumers two evaluation functions can be drawn whereas the consumer in d will choose the lower curve at its technological location. The technological location \bar{d} of the consumer, which is indifferent between j and $j + 1$, can be calculated as:

$$\begin{aligned} p_{j,t-1} + d &= p_{j+1,t-1} + (d_{j,j+1,t}^{tech} - d) \\ \Rightarrow \bar{d} &= \frac{p_{j+1,t-1} - p_{j,t-1} + d_{j,j+1,t}^{tech}}{2} \end{aligned} \quad (4.13)$$

⁵In the case of a dominated sub-market (see below) the price in the last period was equal to $p_{j,t-1} = 0$. Here the consumers assume that the price is equal to the average price in the last period: $\hat{p}_{j,t} = (\sum_j p_{j,t-1})/m_{t-1}$.

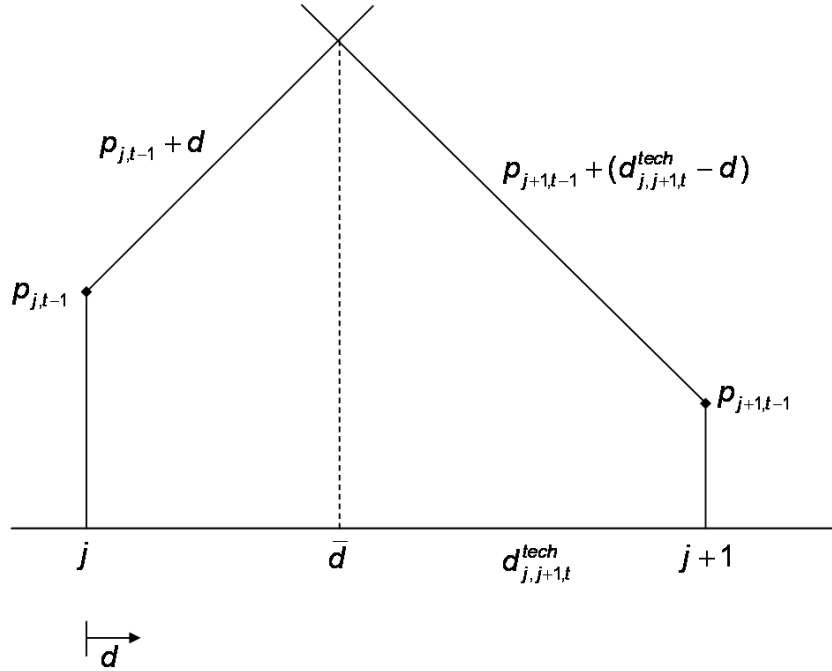


Figure 4.7: Market choice of consumers.

From this formula one can see that the lower $p_{j,t-1}$, the higher $p_{j+1,t-1}$ or the higher $d_{j,j+1}^{tech}$ the greater becomes \bar{d} , which means that the more consumers are attracted to product variant j . The emergence of prices and technological distances is given by the strategic behavior of firms concerning their market entry and exit as well their investments in process and product innovations. It is also worth noticing that even if a firm is monopolist on a market j , his quantity decision (and therefore price decision) is not independent of the neighboring markets, because high prices would convince many consumers to change their demand from the monopolistic to a neighboring market. Beside competition *in the sub-market* the substitutability of product variants enforces competition *between sub-markets*.

While the technology space is understood as a circle, every sub-market of the industry may attract consumers from two sides. Additionally it has to be considered that not only the direct technological neighbors offer the best conditions (the highest evaluation value) for a consumer. A sub-market may be dominated by another market if the price of another market plus the technological distance between those markets is smaller than the price of the dominated market. In Figure 4.7 the sub-market $j + 1$ would be dominated by j if $p_{j+1,t-1} > p_{j,t-1} + d_{j,j+1}^{tech}$. For this the relevant markets for each sub-market have to be detected, whereas the relevant markets are the nearest *not* dominated markets as the technological distance increases.

Figure 4.8 shows an example of a technology space with different prices. One can see that sub-market $j + 1$ is dominated by $j + 2$. Because of that no consumers would

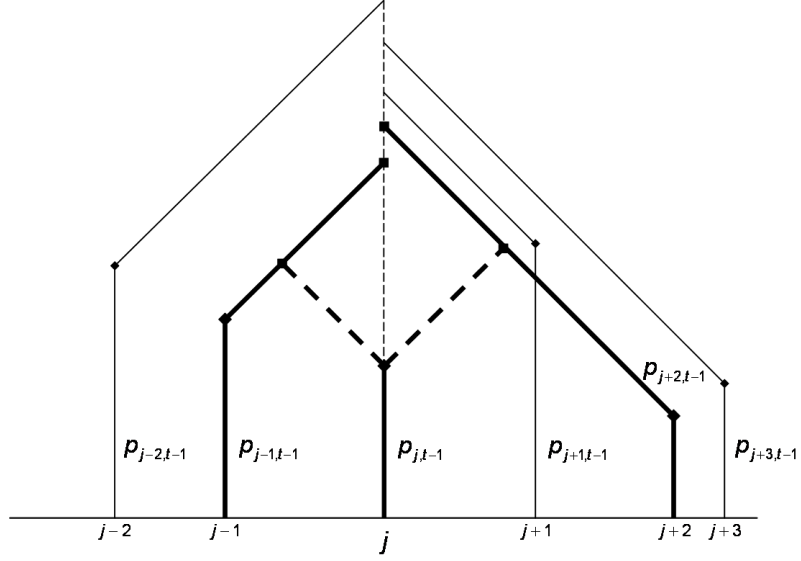


Figure 4.8: Relevant markets.

choose products of sub-market $j + 1$ and therefore $j + 1$ cannot be a relevant market for j . The straight line of $j + 3$ is above the straight line of $j + 2$ and therefore the next relevant market $j+$ in clockwise direction for market j is $j + 2$. The relevant market $j-$ against clockwise direction for market j is $j - 1$, because this is the first not dominated sub-market.

Each consumer has an individual budget that he is willing to spend on products from this industry. With the relevant sub-markets $j-$ and $j+$ and a given budget B_m one can compute the budget $B_{j,t}$ for a sub-market j at time t as the sum of all attracted consumers times a parameter B_m indicating individual demand:

$$B_{j,t} = \left(\underbrace{\frac{p_{j-,t-1} - p_{j,t-1} + d_{j-,j,t}^{tech}}{2}}_{\bar{a}_{j,t}} + \underbrace{\frac{p_{j+,t-1} - p_{j,t-1} + d_{j,j+,t}^{tech}}{2}}_{\bar{b}_{j,t}} \right) \cdot B_m \quad (4.14)$$

With the calculation of the budgets $B_{j,t}$ by the consumers, the selection of the sub-markets is finished. As shown in the overview the firms then continue while setting their output quantities which will then be considered in the market clearing phase. Let us denote $X_{j,t}$ as the sum of all output quantities of all firms on sub-market j in period t . Given the total output $X_{j,t}$ and the budget $B_{j,t}$, one can calculate the emerging price $p_{j,t}$ for these product variant in the market clearing phase by:

$$p_{j,t} = \frac{B_{j,t}}{(X_{j,t})^{\epsilon_{j,t}}} \quad (4.15)$$

In previous models (e.g. Nelson and Winter, 1982; Jacoby, 2005) it was shown that this type of inverse demand function is useful for simulation models. Here the price $p_{j,t}$ on a market j depends on the budget $B_{j,t}$ divided by the total output on the sub-market $X_{j,t} = \sum_j x_{i,j,t}$ to the power of the price elasticity of demand $\epsilon_{j,t}$, which is for simplicity assumed to be equal to one: $\epsilon_{j,t} = 1$.⁶ The inverse demand function can be received from the maximization of an utility function, which increases in quantities (e.g. $U(x_{h,j,t}) = x_{h,j,t}$), with respect to the budget constraint ($p_{j,t} \cdot x_{h,j,t} \leq B_m$). For example in Nelson and Winter (1982) the formula $p_t = 67/X_t$ was used, which is a direct application of this function with a constant budget $B_{j,t} = 67$. The chosen inverse demand function is suitable for simulation models because, even if the agents do not have appropriate expectations or the technological space changes very abrupt, for every given output a price can be computed without having the problems of intersection points with the axis.

In order to perform a welfare analysis we develop a consumer surplus function. The consumer surplus for every sub-market j depends on the range of attracted consumers indicated by $\bar{a}_{j,t}$ and $\bar{b}_{j,t}$ from equation (4.14), the actual price $p_{j,t}$ and a consumer specific maximum price $p_{j,t}^{max}(a)$. This latter value indicates the maximum price a consumer located in a would pay on sub-market j . If the price $p_{j,t}$, on this sub-market exceeds this level, the consumer in a would buy a product variant from the next neighboring relevant markets. Which sub-market the consumer will choose depends on the prices, the technological distances between the markets and of course on the technological location of the consumer. The consumer surplus for each market $CS_{j,t}$ is therefore the space between the actual price $p_{j,t}$ the consumers pay for market j and the maximum price $p_{j,t}^{max}(a)$, which sets the limit for a consumer choosing this market, of the demand function. The resulting consumer surplus of the industry CS_t is understood as the sum of all sub-market specific values: $CS_t = \sum_j CS_{j,t}$. See Appendix (A.1) for further details and the calculation of consumer surplus.

Total welfare W_t can be defined as the sum of consumer surplus CS_t and producer surplus PS_t , which is the sum of profits and fixed cost over all firms in the industry (see e.g. Tirole, 1988; Pindyck and Rubinfeld, 2005).

Therefore with given consumer surplus CS_t , the set of served markets $M_{i,t}$, profits $\Pi_{i,j,t}$ and fixed cost F_i by firm i , we define the welfare in period t as:

$$W_t = CS_t + PS_t = CS_t + \sum_i \sum_{j \in M_{i,t}} (\Pi_{i,j,t} + F_i) \quad (4.16)$$

⁶A more complex formulation of the inverse demand function with $\epsilon_{j,t} \neq 1$ would not allow an analytical calculation of the output quantities, see Section 4.3.2 for more details.

Although the concept of welfare is still being debated⁷ and the formalization in this work might provoke some criticism due its ad-hoc assumptions, welfare provides a useful aggregated indicator of the benefits for producers as well as for consumers in the model.

4.3 Decisions of the Firms

Firms act according to routines in the tradition of evolutionary modeling (see Nelson and Winter, 1982). The routines are heterogeneous because each firm may put different weights on certain factors and because firms only have limited information. Firms do have an idea of the technology space with the technological distances between sub-markets and are well informed about their own cost structures and the budget for each product variant. Firms can calculate their benefits from knowledge spillovers and they can imagine how much their benefits from learning might change with a different geographical location. But firms do not know the costs and strategies of the competitors and they are not able to anticipate the consumer decisions about the substitutability of product variants in the industry.

With respect to proximity firms set a geographical location by moving between agglomeration and periphery. Here firms have to decide whether it is best to protect their knowledge or to take part in the learning process in the agglomeration. Technological proximity is affected by investments in product and process innovations whereas the height and the technological area of the resulting knowledge in comparison with their competitors' knowledge determines the economic performance of the firms. A formal description of the firm decisions allows a study of firm strategies in different environments and their economic gains. The following section starts with the choice of sub-markets by the firms.

4.3.1 Market Entry and Exit

The total number of firms in the industry n is assumed to stay constant. But the number of firms who are active on a certain sub-market is determined endogenously. The change in the market portfolio a firm holds is modeled as a sequence of rule-based market exit and entry decisions. The exit and entry rules rely on an evaluation of all existing markets carried out at the beginning of each period. It is assumed that at the end of a period all firms have an idea of the public technology space.

In order to keep the model as simple as possible the evaluation for market entry depends only on the profitability and on the technological distance to the firm's own main technological focus. As a proxy for profitability the size of the market niche

⁷A broad overview of and an application to optimal taxation can be found in Auerbach (1985).

is taken: The greater the technological distances to the neighboring markets, the more attractive is a sub-market, as it can potentially attract many consumers. The firm's own technological focus l is the technology with the greatest knowledge stock: l from $\max_j \{RD_{i,j,t}^{proc}\}$. For this the evaluation $v_{i,j,t}$ of a sub-market j is given by:

$$v_{i,j,t} = \left(\frac{d_{j,j+1,t}^{tech} + d_{j-1,j,t}^{tech}}{\max_j \{d_{j,j+1,t}^{tech} + d_{j-1,j,t}^{tech}\}} \right)^{\frac{\delta_{i,\Pi}}{(\delta_{i,\Pi} + \delta_{i,T})}} \cdot \left(\frac{1}{1 + d_{j,l,t}^{tech}} \right)^{\frac{\delta_{i,T}}{\delta_{i,T} + \delta_{i,\Pi}}} \quad (4.17)$$

Both terms in brackets are chosen such that the result lies in the interval $[0,1]$, which sets the boundary of the evaluation function to $v_{i,j,t} \in [0, 1]$. The sum of the exponents is chosen to be equal to 1. The exponents are important parameters of the firm's diversification strategy since they represent the weights assigned to possible profits ($\delta_{i,\Pi}$) and technological specialization ($\delta_{i,T}$). The evaluation function is also in line with Bain (1956), who argues that entrants' expectations are determined by the height of pre-entry profits relative to entry barriers. In this case the size of the market niche is a proxy for profits and the possibilities to develop knowledge for process innovations determine the degree of the entry barrier. Another interpretation of the evaluation function can be done in connection to the management literature mentioned in Section 2.1. Hence, the firm's own technological focus is similar to the concept of a firm-specific core competence (Prahalad and Hamel, 1990) and only the opportunity for great profits can convince firms to extend their knowledge portfolio in new areas. The article by Breschi et al. (2003) discusses whether firms follow a more profit-oriented or knowledge-related strategy in their innovation activities. The authors find empirical evidence that firms extend their innovative activities across knowledge-related technological fields as a consequence of learning processes. Apart from that, the two strategies of their approach are in line with our assumptions.

After a successful product innovation the innovating firm becomes monopolist on this market for τ periods and therefore no other firms can enter. After that period the market becomes available and every other firm may enter. To make the entry decision the firm ranks all available markets it does not currently serve according to their evaluations and determines the best existing non-served market as the entry candidate. The entry candidate is added to the portfolio if $v_{i,l,t} > \kappa_{i,en}$ and if the candidate does not belong to the set of previously served markets $M_{i,t-1}$. The parameter $\kappa_{i,en} > 0$ is an inertia parameter and represents the aggressiveness of the firm's entry policy. The firm can only enter in one sub-market every period.

$$\max_{l \notin M_{i,t-1}} \{v_{i,l,t}\} > \kappa_{i,en} \quad (4.18)$$

The exit decision of the firm is determined solely on the sum of profits of the

last τ_{ex} periods. The firm will choose the market with lowest value for $\sum_{\tau=1}^{\tau_{ex}} \Pi_{i,j,t-\tau}$ and will exit this sub-market if the sum of the profits is below the credit line S^0 respectively the current saving plus the credit line $S^0 + S_{i,t}$ times the firm-specific parameter $\kappa_{i,ex}$:

$$\min_{l \in M_{i,t-1}} \sum_{\tau=1}^{\tau_{ex}} \Pi_{i,j,t-\tau} < -\kappa_{i,ex} \cdot \min\{S^0, S^0 + S_{i,t}\} \quad (4.19)$$

The knowledge of this specific technology remains in the firm. The firm exits up to one sub-market a period and chooses the market with the greatest losses.

4.3.2 Quantity Decisions

The quantity decisions are modeled similar to Dawid and Reimann (2005, 2007). Firms try to maximize their profit in each sub-market, but they are restricted by imperfect information. Firms believe that all producers in the sub-market change their output quantity by the same factor. They know the actual budget on each sub-market and therefore the demand function for each sub-market. But firms do not have perfect information about the effects of prices on the consumer market selection process in the next period. The aggregate output quantities and the number of firms in all sub-markets at $t-1$ can be observed by all producers including those that were not active in this market. Each firm has in all periods perfect information about its own fixed cost F_i and marginal cost $c_{i,j,t}$ of production of all product variants. Firms however do not know other firms' cost structures. With this information they can calculate their optimal production quantity in each sub-market.

Given the set of sub-markets $M_{i,t}$, firm i tries to maximize their profits by choosing the optimal output quantity $x_{i,j,t}$ in each sub-market with the given profit function $\Pi_{i,j,t}$:

$$\max_{x_{i,j,t}, j \in M_{i,t}} \Pi_{i,j,t} = [p_{j,t} \cdot x_{i,j,t} - c_{i,j,t} \cdot x_{i,j,t}^2 - F_i], \quad (4.20)$$

subject to the constraint that current production has to be paid for by the current stock of savings $S_{i,t}$:

$$S_{i,t} \geq F_i \cdot |M_{i,t}| + \sum_{j \in M_{i,t}} (c_{i,j,t} \cdot x_{i,j,t}^2). \quad (4.21)$$

The corresponding first-order conditions with the Lagrange multiplier $\mu_{i,t} \geq 0$ of

the firm's budget constraint are:

$$p_{j,t} + x_{i,j,t} \cdot \frac{\partial p_{j,t}}{\partial x_{i,j,t}} - 2 \cdot c_{i,j,t} \cdot x_{i,j,t} (1 + \mu_{i,t}) = 0 \quad \forall j \in M_{i,t} \quad (4.22)$$

Due to the limited information about the competitor's production cost and output quantities, firms cannot simply determine the Nash equilibrium of this quantity setting game. Rather they use some heuristic approximations to determine their output quantity. For setting the quantity output several steps have to be taken.

First, the firms believe that all producers in the sub-market j change their output quantity by the same factor λ . For this the total estimated output $\hat{X}_{j,t}$ on sub-market j is given by:

$$\hat{X}_{j,t} = \lambda \cdot \sum_i x_{i,j,t-1} = \lambda \cdot X_{j,t-1}. \quad (4.23)$$

Second, the firms expect that all firms change their output in the same way they would do: $\lambda = \lambda_{i,j,t}$. Building on the inverse demand function (4.15) they expect the following prices:

$$\hat{p}_{j,t} = \frac{B_{j,t}}{\lambda \cdot X_{j,t-1}} \quad (4.24)$$

Last, firms have an idea of the functional form of the inverse demand function. Thus firms can approximate the partial derivative of the inverse demand with respect to $x_{i,j,t}$ as:⁸

$$\frac{\partial \hat{p}_{j,t}}{\partial x_{i,j,t}} = -\frac{B_{j,t}}{(\lambda \cdot X_{j,t-1})^2} \quad (4.25)$$

With this information the firms can calculate their optimal production quantity in each sub-market. For firms that have been in sub-market j in period $t-1$ inserting these expression into (4.22) gives the output quantity $x_{i,j,t} = \lambda \cdot x_{i,j,t-1}$ with:

$$\lambda = \frac{1}{X_{j,t-1}} \cdot \sqrt{\frac{B_{j,t}(X_{j,t-1} - x_{i,j,t-1})}{2 \cdot c_{i,j,t} \cdot x_{i,j,t-1} \cdot (1 + \mu_{i,t})}} \quad (4.26)$$

It becomes obvious from this expression that the actual rates of changes are heterogeneous. Thus quantities depend on the consumer budgets, the market share of the firm in the last period, the production constraint, and on the knowledge for process innovations, which is incorporated in the marginal cost $c_{i,j,t}$.

⁸They assume that $p_{j,t} = \frac{B_{j,t}}{F(x_{i,j,t})}$ whereas $F(x_{i,j,t})$ is a linear function in $x_{i,j,t}$, e.g. $F(x_{i,j,t}) = \lambda \cdot X_{j,t-1} - x_{i,j,t-1} + x_{i,j,t}$. The derivative with respect to $x_{i,j,t}$ would be $\frac{\partial p_{j,t}}{\partial x_{i,j,t}} = -\frac{B_{j,t}}{F(x_{i,j,t})^2} \cdot 1$.

A firm which did not produce variant j in period $t - 1$ but added this sub-market in t first tries to estimate the change of output quantity of the incumbents and determines its optimal quantity based on this. The expected rate of change of output of the incumbents in the market is determined analogous to equation (4.26) where $x_{i,j,t-1}$ is replaced by the average output of a producer of variant j in period $t - 1$. $N_{j,t-1}$ should be the set of producers in the sub-market j in the period $t - 1$. The average output on this market can therefore be written as:

$$x_{i,j,t-1} = \frac{\sum_{k \in N_{j,t-1}} x_{k,j,t-1}}{|N_{j,t-1}|} = \bar{x}_{i,j,t-1} \quad (4.27)$$

The expectations of firm i about total output in t in such a case is $\hat{X}_{j,t} = \lambda \cdot X_{j,t-1} + x_{i,j,t}$. Inserting into (4.22) implies a production quantity of $x_{i,j,t} = \lambda \cdot \bar{x}_{i,j,t-1}$ with:

$$\lambda = \frac{1}{(X_{j,t-1} + \bar{x}_{i,j,t-1})} \cdot \sqrt{\frac{B_{j,t} \cdot \bar{x}_{i,j,t-1}}{2 \cdot c_{i,j,t} \cdot \bar{x}_{i,j,t-1} \cdot (1 + \mu_{i,t})}} \quad (4.28)$$

Finally there is a minimum quantity $x_{min} > 0$ which has to be produced by any firm which decided to keep this sub-market in its portfolio. If the result of the quantity calculations is below this level the firm still produces x_{min} . Also in the initial period and every time when a sub-market is founded by a product innovation the quantity x_{min} is produced by the founder. This is also the case if a firm enters an empty market. In the special case of monopoly equation (4.22) would lead to $x_{i,j,t} = 0$ and therefore the minimum quantity is chosen.

Monopolist (e.g. after successful product innovation)	x_{min}
Incumbent	$x_{i,j,t} = \lambda \cdot x_{i,j,t-1}$ with $\lambda = \frac{1}{X_{j,t-1}} \cdot \sqrt{\frac{B_{j,t}(X_{j,t-1} - x_{i,t,t-1})}{2 \cdot c_{i,j,t} \cdot x_{i,j,t-1} \cdot (1 + \mu_{i,t})}}$
Entrant in a Market with Incumbents	$x_{i,j,t} = \lambda \cdot \bar{x}_{i,j,t-1}$ with $\lambda = \frac{1}{(X_{j,t-1} + \bar{x}_{i,j,t-1})} \cdot \sqrt{\frac{B_{j,t} \cdot \bar{x}_{i,j,t-1}}{2 \cdot c_{i,j,t} \cdot \bar{x}_{i,j,t-1} \cdot (1 + \mu_{i,t})}}$

Table 4.1: Firms' decisions concerning output quantities.

All quantities for the sub-markets are calculated based on these formulas until the constraint that current production has to be paid for by the current stock of savings, is fulfilled. For a better overview Table 4.1 sums up the firms' output decisions.

4.3.3 Investments in Geographical Location

Starting from a random location the firms may decide to change their geographical location from core ($d_{i,t}^{geo} = 0$) to periphery ($d_{i,t}^{geo} = 1$) or vice versa. As argued in Section 2.2 the change of geographical proximity can occur very sudden, which in the model means that the decision can be made every period. The shifting of the location leads to sunk cost c_{fix}^{geo} due to expenses for transferring the R&D facilities. These costs are constant in order to keep the model simple.

The investments occur when a location is changed:

$$I_{i,t}^{geo} = \begin{cases} c^{geo}, & \text{if } d_{i,j,t}^{geo} \neq d_{i,j,t+1}^{geo}; \\ 0, & \text{otherwise.} \end{cases} \quad (4.29)$$

For the evaluation of the two location alternatives two factors seem to be important. First, the main advantage of a headquarter at the core lies in the learning effect through spatially transferred knowledge. But knowledge spillovers are a threat for the firm's own core competence in knowledge. For this a second point aims at the own technological leadership. Because knowledge for product innovations is only a first step to form a competitive advantage, the knowledge stock for process innovation $RD_{i,j,t}^{proc}$ (and the corresponding spillover $SP_{i,j,t}^{proc}$) is the main indicator for a knowledge competence. Thus for the evaluation of the location only this type of knowledge is considered. The evaluation function for the geographical locations should be written as:

$$v_{i,t}^{geo} = \left[\mathbb{E} \left(\frac{RD_{i,j,t}^{proc}}{RD_{j,t}^{proc}} \right) \right]^{\frac{\delta_{i,RD}}{\delta_{i,RD} + \delta_{i,SP}}} \cdot \left[\mathbb{E} \left(\frac{SP_{i,j,t}^{proc}(d_{i,j,t}^{geo} = 1)}{SP_{i,j,t}^{proc}(d_{i,j,t}^{geo} = 0)} \right) \right]^{\frac{\delta_{i,SP}}{\delta_{i,RD} + \delta_{i,SP}}} \quad (4.30)$$

The evaluation for the geographical location $v_{i,t}^{geo}$ of firm i lies in the interval $[0, 1]$, where a result of $v_{i,t}^{geo} = 0$ stands for a strong incentive to set the headquarter of the company at the core ($d_{i,t}^{geo} = 0$). The symbol \mathbb{E} should stand for the arithmetic mean over all values greater than zero.

As mentioned above the first term takes account of the possible loss of a technological core competence. Hereby the firm i 's knowledge is divided by the maximum knowledge of another firm in this market where $RD_{j,t}^{proc} = \max_i \{RD_{i,j,t}^{proc}\}$. If the potential loss is great, the firm would have the incentive to choose a location far away from the competitors. The second term considers the effect of the knowledge

spillover. The numerator is the sum of the internal knowledge spillover which would occur in every location. The denominator is the sum of the internal and external spillover. If a firm profits a lot from external spillovers, the firm would have an incentive to locate inside the cluster.

Like in the evaluation function of market entry (see equation (4.17)) the firm-specific parameters $\delta_{i,RD}$ and $\delta_{i,SP}$ represent firm strategy. The parameters weight the different terms such that heterogeneous firm strategies can be reproduced. As in the evaluation of markets there exists an inertia parameter $\kappa_{i,S}$. Firms will for example change their geographical location from periphery to core if $v_{i,t}^{geo} \leq \kappa_{i,S}$ and if their savings are higher than the shifting cost $S_{i,t} > I_{i,t}^{geo}$. If firm i has a location on the periphery ($d_{i,j,t}^{geo} = 1$), the firm will choose their geographical distance for the next period as follows:

$$d_{i,t+1}^{geo} = \begin{cases} 0, & \text{if } v_{i,t}^{geo} \leq \kappa_{i,S} \wedge S_{i,t} > I_{i,t}^{geo}; \\ 1, & \text{otherwise.} \end{cases} \quad (4.31)$$

If firm i is at the core ($d_{i,t}^{geo} = 0$), it will choose its geographical distance for the next period as follows:

$$d_{i,t+1}^{geo} = \begin{cases} 1, & \text{if } v_{i,t}^{geo} > \kappa_{i,S} \wedge S_{i,t} > I_{i,t}^{geo}; \\ 0, & \text{otherwise.} \end{cases} \quad (4.32)$$

In both cases the shift of location has to be funded by the firm's savings $S_{i,t}$. If the firm cannot afford this, the firm's location does not change.

4.3.4 Investments in Research and Development

At the end of a period each firm decides on its investments in product and process innovations. Both investments $I_{i,j,t}^{proc}$ and $I_{i,j,t}^{prod}$ increase the corresponding knowledge stocks $RD_{i,j,t}^{proc}$ respectively $RD_{i,j,t}^{prod}$ and depend on the current profits of the firm $\Pi_{i,t}$. The R&D investment quota for product innovation is denoted by q_i^{prod} and the quota for process innovation is q_i^{proc} . The investments for product innovations are given by:

$$I_{i,j,t}^{prod} = q_i^{prod} \cdot \Pi_{i,t}, \quad (4.33)$$

and for process innovations by

$$\sum_j I_{i,j,t}^{proc} = q_i^{proc} \cdot \Pi_{i,t}. \quad (4.34)$$

Since process investments lead to a reduction of per unit cost of production, the

firm allocates these funds to the different sub-markets proportional to an adjusted expression of its current output in each market:

$$I_{i,j,t}^{proc} = q_i^{proc} \cdot \Pi_{i,t} \cdot \frac{x_{i,j,t}}{\sum_{k \in M_{i,t}} x_{i,k,t}} \quad (4.35)$$

A product innovation is seen as an alternative to market entry: In order to extract rents on a profitable market a new market is founded next to the existing one. For this the evaluation function for product innovations $v_{i,j,t}^{prod}$ is equal to the evaluation of markets, see equation (4.17). The only difference is that now all markets are considered, whereas the decision for market entry took only those markets into account which were not served by firm i and entry was not prevented by patent protection. Firm i will invest all its expenditures for product innovations in the market l with the highest evaluation: $I_{i,l,t}^{prod} = q_i^{prod} \cdot \Pi_{i,t}$, but only if $v_{i,j,t}^{prod} > 0$.

The interpretation behind these fixed rules for research and development investments sees the behavior of firms to be short-term oriented. Firms are understood to change expenses for research projects very abruptly in accordance with their economic success in each period. Firms in reality might also follow long-term goals in their R&D strategy and firms' R&D investments might depend not on profits but on revenues. On the other hand, the assumed rules for the investments for process innovations depend on product quantities and for product innovations on potential market niches and the firm's own technological focus. As these values are likely not to change every period, there is some continuity in the R&D strategy of the firm. This continuity emerges mostly because of the assumed evaluation functions and not by the expenses for R&D. Therefore, the intensity of R&D might change very suddenly, but the focus of the innovation efforts is rather constant over time. As we will see in Section 5.1.1, the parameters for the share of R&D investments on profits can be calibrated with the help of firm level data.

4.4 Market Clearing

With all quantity outputs $x_{i,j,t}$ prices can be calculated for all sub-markets. With the cost functions every firm is able to derive their overall profit $\Pi_{i,t} = \sum_{j \in M_{i,t}} \Pi_{i,j,t}$ from the profits $\Pi_{i,j,t}$ on every sub-market which are given by:

$$\Pi_{i,j,t} = (x_{i,j,t} \cdot p_{j,t} - c_{i,j,t} \cdot x_{i,j,t}^2 - F_i) \quad (4.36)$$

All firms start with initial savings of S^0 . Every period they earn total profit $\Pi_{i,t}$ but also have to make their investments on process innovations $I_{i,j,t}^{proc}$, product innovation $I_{i,j,t}^{prod}$ and eventually on the change of location $I_{i,t}^{geo}$. The savings for the

next period should be expressed by the following formula while ρ stands for the interest rate:

$$S_{i,t+1} = (1 + \rho)S_{i,t} + \Pi_{i,t} - I_{i,t}^{geo} - I_{i,j,t}^{prod} - \sum_{j \in M_{i,t}} I_{i,j,t}^{proc} \quad (4.37)$$

Firms are able to rent money up to their starting level of savings S^0 . If the savings of a firm are less than $-S^0$, the firm is bankrupt. All knowledge of bankrupt firms is lost. Bankrupt firms are replaced in the industry with new firms with new savings S^0 and the same knowledge as the technological leader, but only in one randomly picked market. The geographical location is hereby chosen randomly. The substitution of bankrupt firms is understood as an entry of a new firm in this industry and a firm would only enter if it had - at least in one technology - the same knowledge as a technological leader. The new firm gets new specific parameters which represent the new strategy. Therefore the total number of firms is constant in the industry but as shown above, the market structure of the sub-markets is determined endogenously.

Chapter 5

Model Verification and Validation

According to Kennedy et al. (2006) model verification is understood as '*solving the model right*'. This means that the computational representation is modeled correctly and matches the abstract model. Model validation is seen as '*solving the right model, meaning that the correct abstract model was chosen and that the model accurately represents the real-world phenomena*' (Kennedy et al., 2006, p. 95). Obviously the result of model validation is not the perfect model, since the perfect model would be the real system itself (Kleijnen, 1995). Model verification and validation are crucial elements for the model development and interpretation process, since they support the plausibility and credibility of the simulation model. For more details to the debate about model verification and validation refer to: Kleijnen (1995); Troitzsch (2004); Sargent (2005); Fagiolo et al. (2006); Kennedy et al. (2006); Windrum et al. (2007).¹

Apart from the formal representation introduced in the last chapter and program debugging, which considered methods like face validation, internal validity, tracing and animation, an accurate choice of the model parameters seems to be the most important objective of the model verification process. Therefore the next step is the introduction of the parameters of the model. Model validation is then performed such that the model outcome is compared to a great number of empirical studies to study how well the results fit real-world data.

5.1 Parametrization of the Model

The discussion of the parameter space completes the description of the model. Therefore this section begins by showing how the values for input parameters are chosen for the simulation exercises. Since only a small number of parameters can be estimated with empirical data, the second part of the section debates the relevance of

¹See also the debate on model replication in e.g. Wilensky and Rand (2007).

the remaining parameters with the help of a sensitivity analysis.

5.1.1 Setting the Parameters

The simulation model employed in this work is rather complex and has a large set of parameters. In particular the parameters of the simulation model for the standard scenario can be found in Appendix A.2 in Tables A.1 and A.2. The model starts every time with a technology space with m_0 technologies, located on a circle with the normally distributed technological distances with mean d_0^{tech} and variance σ_{tech}^2 (but at least equal to 0.01) between those technologies. In total the industry consists of $n = m_0/2$ firms which interact on the product markets. The geographical location of the firms is chosen randomly. Each firm starts with a randomly generated knowledge in one of the technologies and is also an active member of the corresponding sub-market. The starting level is normally distributed around mean RD^0 with the variance σ_0^2 (but at least equal to 0.01). Thus on every sub-market there are exactly two firms active in the first period. Firms are able to borrow money up to their starting level of savings S^0 . If the savings of a firm are less than $-S^0$, the firm is bankrupt and the knowledge of bankrupt firms is lost. Bankrupt firms are replaced in the industry with firms, that have new savings, the same knowledge as the technological leader in one randomly picked market and a random geographical location, see Section 4.4. The new firm gets new specific parameters which represent the new strategy. Therefore, the total number of firms is constant in the industry, but the market structure of the sub-markets is determined endogenously through market entry and exit.

Including the initial conditions four types of parameters can be distinguished. First, the parameters determining the basic characteristics of the industry (number of firms, individual demand, minimum production output, interest rate, time as monopolist). The second group contains technological parameters (costs, thresholds for product innovations, starting values for technological distances, number of technologies and knowledge for process innovation). Third, strategy parameters determining the behavior and capabilities of the firms in the industry (learning curve effects, weights and thresholds in the functions evaluating markets, investments in product and process innovation, fixed cost, initial values for savings). And the last group of parameters describes the length and the repetition of the simulations. Table 5.1 allocates the parameters to the defined groups.

In order to derive qualitatively robust results which do not hinge on particular parameter settings, we base our observations on batches of 100 simulation runs carried out for different parameter constellations. The industry structure and technology parameters are fixed across these runs but parameters of the second type are

Group	Parameters
Industry characteristics	$n, B_m, x_{min}, \rho, \tau$
Technological Environment	$c^{min}, c^{ini}, c, d, e, d_0^{tech}, \sigma_{tech}^2,$ m_0, RD^0, σ_0^2
Firm strategy	$\alpha_i, \beta_i, \kappa_{i,en}, \kappa_{i,ex}, \tau_{ex}, \kappa_{i,S}, \delta_{i,\Pi}, \delta_{i,SP},$ $\delta_{i,RD}, \delta_{i,T}, q_i^{prod}, q_i^{proc}, F_i, S^0$
Simulation	T, Runs

Table 5.1: Grouping of parameters.

mostly² chosen stochastically from certain predefined ranges for each firm in each run. The initial conditions concerning the starting values of knowledge for each firm and the definition of the technology space are set up randomly, too. Additionally the time horizon T was kept fixed, but every presented result is tested for its stability considering a longer time horizon. The mentioned approach allows us to test whether the impact that a restriction of the range of selected strategy parameters has on various variables of interest is statistically significant across stochastically chosen profiles of the other parameters. In the following we directly calibrate some parameters in order to reduce the degrees of freedom of the model (see Fagiolo et al., 2006; Windrum et al., 2007).

The parameters are chosen such that the model was able to find reasonable and robust results. For example the number of radical product innovations is controlled to be much lower than the number of incremental product innovations. The capabilities of the firms to learn and generate knowledge for process innovations were set in such a way that it is possible to reach the lowest possible production cost within half of the simulated time horizon. The aggregated budget of all consumers in the industry is determined not only by individual demand but also by the technological distances in the technology space, see equation (4.14). Hence, the initial aggregated budget of the industry has to be high enough in order to allow for positive profits of the firms. The overall budget of the industry is an increasing and convex function in the number of radical product innovations which in parallel increase the total circumference of the technological circle. This pattern emerges endogenously from

²There are two exceptions: The starting level of savings S^0 and the number of periods τ_{ex} considered for market exit, which are equal for every firm and simulation run.

the assumptions of the model without any additional parameters. The technological distances again are significant for the level of knowledge spillovers, see equation (4.10). In this context it is important that the possible knowledge spillover can reach approximately the same magnitude as the investments in product or process innovations. The parameters which describe firm strategies are in general no problem for getting plausible results because most of the structure is given by the evaluation functions in equations (4.17) and (4.30). The parameters which determine the weights put on different factors are chosen from the interval $[0,1]$. It does not matter how the boundaries of the interval are chosen as long they are equal for all firms. If numbers from different intervals are allocated to the strategies of the firms, it can be said that firms follow different strategies. The same arguments hold for the parameters which determine the thresholds for firm strategy. A last point aims at the time restriction given due to the use of an ordinary PC and the programming language MATLAB, which limits the number of possible interacting agents, the number of repetitions and the length of the simulation runs.

In one case it was possible to calibrate the parameters to empirical data: The expenses of firms for product and process innovations (q_i^{prod}, q_i^{proc}) were chosen to be in total approximately 5% of the revenues of firms. The division of the investments in innovations was set to be on average 30% for process and 70% for product innovations. These parameter values are in line with recent empirical studies of German firm data (Legler et al., 2004; Rammer et al., 2004) and with data from US in the 1970s and 80s (see Chapters 5-9 in Griliches, 1998). In the model the investments are calculated proportionally to firm profits, see equations (4.33) and (4.34). The parameters were set to be on average equal to $q_i^{prod} + q_i^{proc} = 0.4$, which leads to investments of approximately 5% of firm revenues. From this one can calculate $q_i^{prod} = 70\% \cdot 0.4 = 0.28$ and $q_i^{proc} = 30\% \cdot 0.4 = 0.12$, which are the mean values of the given intervals with uniform distribution.

In order to evaluate the model outcome based on the input parameters several simulation runs are considered. The interpretation of the results is based on graphical analysis (for example a boxplot or a histogram at a certain time, the graph of the mean for a variable over all simulation runs over time) and on statistical testing. Each model outcome is tested upon their time stability indicating whether the outcome persists at a longer time horizon or not.

5.1.2 Sensitivity Analysis

The arguments discussed so far add constraints to the parameter space of the model. But there still remain parameters which could be crucial for the results of the model and which are chosen from a quite big range. Many of these parameters will be the

topic of simulation exercises in the following chapters (e.g. firm strategies in Chapter 6 and industry characteristics in Chapter 7.2), but in order to get a broader picture critical parameters are identified and their impact on certain main characteristics of the industry are analyzed in a sensitivity analysis.

The methodology for evaluating the impact of several input parameters on the model output is based on a screening design which provides a list of factors ranked in order of decreasing importance. Several screening designs are discussed in the literature, but here the analysis is based on the methodology of Morris (1991).³ The design by Morris and other forms of sensitivity analysis useful for agent-based simulation models can be found in Campolongo et al. (2000) and Saltelli et al. (2004).

Morris's experiment design varies one factor at a time which is chosen from a discrete number of levels for each input factor. Four different levels are chosen for each input parameter and their values are given in Table 5.2. Morris (1991) argues that the estimation of the relevance of each input parameter should be based on two measures for each parameter: The first measure μ describes the overall effect of this parameter on model output and the other measure σ estimates second- and higher-order effects in which the factor is involved. The Morris design starts by randomly creating a matrix which gives the experiment plan in the form of values for all input factors. For every simulation run one single parameter is modified. Based on the comparison of the model outcome before and after the parameter change an elementary effect of this particular input factor is calculated. Although the method relies on a local sensitivity measure (the elementary effect), it can be understood as a global method, because the measures μ as the mean and σ as the standard deviation of the elementary effects are calculated upon several different areas in the input space (see also Chapter 4 in Saltelli et al., 2004). A revised version of the Morris method suggests the usage of the absolute values for the calculation of the mean (p. 93, Saltelli et al., 2004). The approach in this work considers this extension and labels the mean of absolute values of the elementary effects as μ^* . The experiment plan can be built with the help of a random number generator and the computation with matrices which can easily be implemented in MATLAB. The results of the method are best shown in a figure of the (μ^*, σ) -space, which will be done after the introduction of the considered input and output variables for the sensitivity analysis.

One aim of the approach in this work is the description of the technological development of an industry. Thus factors with a potential high impact on the outcome of innovations are important. In the model the evolution of the knowledge for process innovations is determined by the parameters α_i and β_i as well by the initial value

³An earlier version of the model was analyzed with the methodology of Cotter (Cotter, 1979; Campolongo et al., 2000) with similar results regarding relevant input parameters.

for process innovation RD^0 . Apart from the knowledge for process innovation the variable costs are determined with the parameters c^{min} and c^{ini} . The parameters α_i and β_i are important for product innovations, too. Additionally the parameter d sets the lower bar for a successful introduction of a radical new product variant. As mentioned above the consumer budget is driven by the initial technological distance d_0^{tech} and the individual budget B_m . Main exogenously given parameters influencing the behavior of firms can be seen in the number of competitors n , fixed cost F_i and initial savings S_0 . As a simulation-specific parameter the number of simulated periods T is incorporated in the analysis. Table 5.2 shows the input parameters and their values taken for the Morris exercise. All firm-specific parameters (α_i , β_i and F_i) indicate the lower boundary of the interval, of which the numbers for the firm capabilities are chosen stochastically.

Number	Parameter	0	1/3	2/3	1
1	α_i	3	3.3333	3.6667	4
2	β_i	0.75	0.7833	0.8167	0.85
3	F_i	0.2	0.2667	0.3333	0.4
4	RD^0	0.15	0.1833	0.2167	0.25
5	d	0.935	0.94	0.945	0.95
6	d_0^{tech}	1	1.6667	2.3333	3
7	B_m	1	2.3333	3.6667	5
8	n	5	8	11	14
9	S_0	5	8.3333	11.6667	15
10	T	100	133	166	200
11	c^{min}	0.1	0.2333	0.3667	0.5
12	c^{ini}	0.3	0.4333	0.5667	0.7

Table 5.2: Input parameters for the Morris sensitivity analysis with the choice of $p = 4$.

After the identification of possible driving parameters one should discuss what simulation results are important to consider for the sensitivity analysis. Indicators for the technological development of the industry are the number of product innovations and the evolution of the average level of process innovations. In order to see the effect of the parameters on geographical and technological proximity the number of firms at the core in percent and the specialization of the industry⁴ of the industry are taken into account. In addition, the effect of a parameter change on welfare is analyzed by examining the average firm profits and consumer surplus which should help to indicate the benefits of consumers.

As an example of the outcome of the sensitivity analysis the result for consumer surplus is shown in Figure 5.1. The diagram of the consumer surplus is chosen be-

⁴The definition of specialization will be given in Section 6.1. At this point specialization of the industry is used as an analysis of the technological proximity.

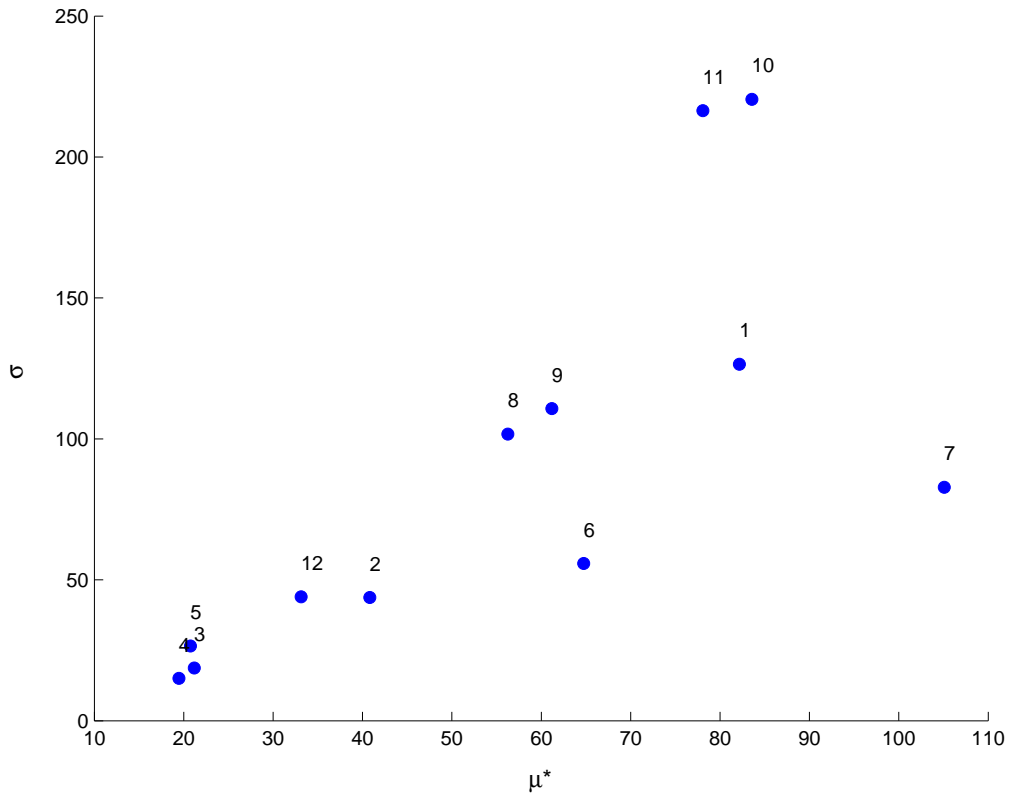


Figure 5.1: The effect of several input parameters on the consumer surplus in the model. (Morris sensitivity analysis of absolute values with sample size $r = 15$.)

cause the interpretation of the output is not that obvious in this situation. Each point represents the sensitivity measures for a single input variable. The numbers correspond with the parameters from Table 5.2. Roughly three groups of parameters can be identified in the picture. The first group (2,3,4,5,12) consists of input parameters which are located close to the origin. According to the Morris analysis a change in these parameters ($\beta_i, F_i, RD^0, d, c^{ini}$) has only a marginal effect on the consumer surplus at the end of the simulation horizon. According to Morris (1991) these parameters are not important for the outcome because they have low values for μ^* and σ . The second group (6,8,9) is separated from the other points and indicates a medium influence on the consumer surplus. This holds for the parameters d_0^{tech} , n and S_0 . The last group (1,7,10,11) exhibits high importance for the outcome of consumer surplus. These parameters stand for a part of the capability to accumulate knowledge (α_i), the budget of each consumer (B_m), the time horizon (T) and the potential to lower production cost (c^{min}). The Morris analysis suggests that these parameters have non-linear effects or are involved in interactions with other factors because they have high values for μ^* and σ . A high value for μ^* and a value close to zero for σ would point toward linear effects. No input parameters in the figure seem to have a purely linear influence.

From the above example the qualitative aspect of the method becomes clear. This could be seen as a possible weakness of the approach. It is very hard to fix the limit of the relevant parameters. For example are the parameters in the middle group (6,8,9) still relevant or not? Here only the outer parameters are considered. It should be added that the figures for the other output variables indicate a much more distinct situation where it is much easier to distinguish between negligible and relevant input parameters. All results of the sensitivity analysis are summarized in Table 5.3.

	Product Innovations	Process Innovations	Profits	Consumer Surplus	Firms at the Core	Specialization
α_i	x			x		
β_i						x
F_i						x
RD^0						
d						
d_0^{tech}	x	x				
B_m	x	x		x	x	
n			x		x	
S_0						
T			x	x		
c^{min}		x	x	x		
c^{ini}						

Table 5.3: Crucial input parameters which drive the corresponding output values are indicated with an 'x'. (Morris sensitivity analysis of absolute values with sample size $r = 15$.)

The sensitivity analysis gives evidence that different input parameters do effect different outcome variables. Some parameters even have a high influence for a range of output factors. Among the latter group are the conditions which describe the demand setting in the industry (the initial technological distance d_0^{tech} and the individual budget B_m). Looking at the effect of production cost the initial mean knowledge for process innovations (RD^0) is negligible whereas the potential to decrease production cost (c^{min}) influences several output values. The number of firms in the industry n modifies the average profits and the percentage of firms in the agglomeration. The time horizon T alters profits and consumer surplus but seems not to alter the outcome for geographical and technological proximity. The firm-specific parameters α_i , β_i and F_i do only have a minor impact on the output although aspects of technological location seem to be modified by them. Other parameters like the threshold for radical product innovations d , the initial level of savings S^0 or the initial level of production cost c^{ini} appear to be irrelevant.

The sensitivity analysis provides a good picture of which input parameters probably drive which model output. Most of the parameters which had a relevant impact on main industry characteristics are kept fixed during the simulation exercises in or-

der to compare model outcome. Overall, the results of the sensitivity analysis are plausible and support the implementation (and verification) of the computational model. An important result is the highly influential role of demand conditions on the technological development of the industry which is in line with the formal assumptions of the industry specification. We will come back to this in Section 7.3, where policy might influence the consumers' demand. Having discussed the aspects of the implementation of the theoretical model, the next section concentrates on the empirical relevance of the model.

5.2 Comparison with Empirics

This section introduces a comparison of the virtual industry, which is represented in the simulation model, with the real world, or, in other words, a comparison to something what many economists think that the real world could be. It may be important to mention that the aim of the theoretical model discussed in this book is not the reproduction of so-called stylized facts (for such a methodology see e.g. Dosi et al., 2006). As discussed in the latter section, the parameters are not calibrated to reproduce statistics but to provide a meaningful picture of an innovative industry.

The idea behind this section is the confrontation of the simulation outcome of the abstract model with observed empirical regularities. The main task is to identify similar patterns of industry development and details in which the theoretical model departs from the observed correlations. Most of the analysis here is qualitative and concentrates on the aspects of the model. Many of the stylized facts found in the literature cannot be discussed simply because they are not modeled (e.g. entry to the industry). The debate is arranged around the topics of firm size and growth, persistence, and an interpretation of competition which is connected to the name Schumpeter. More specific topics about firm strategy and economic policy in connection to related empirical studies are presented in the applications Part III of this book.

The basis for the validation of the model are various empirical studies conducted in connection with the Industrial Organization approach. This approach tried to identify certain measures of market structure, conduct and performance. Main results of this strand of literature are very well summarized in Schmalensee (1989) and Caves (1998). More recent surveys add to the traditional topics a discussion of the influence of innovation on the development and the evolution of industries (see Cohen, 1995; Geroski, 1995; Jensen and McGuckin, 1997; Bartelsman and Doms, 2000; Marsili, 2001). See also the work by Klette and Kortum (2004) for a recent overview of stylized facts.

Table 5.4 provides a summary of the stylized facts considered and the ability

Stylized Facts	Evidence in the Model
No normal firm size distribution	Yes
No normal firm growth distribution	Yes
R&D productivity decreases with firm size	Yes
Persistent profitability differences	Not stable, but increasing
Persistent market concentration	Not stable, but increasing
Persistent firm productivity differences	Not stable, but increasing
Innovative firms replace less innovative firms	Yes
Positive correlation between entry and exit rates	Yes
Product market life cycle patterns	Yes, but not very clear
Clustering of innovations in time and space	Yes

Table 5.4: Stylized facts and the reproduction in the simulation model.

of the simulation model to reproduce these regularities. The comparison with the empirics underlines the fact that the model generates reasonable firm size and growth distributions and is in line with the view that R&D productivity is declining with firm size. The model proves to be evolutionary because it captures the idea that innovative successful firms expand at the expense of less successful firms, which in the longer run leads to increasing differences in profitability, market concentration and firm productivity. The indicated results depart from empirical findings, which mostly suggest stable differences of the firm and market characteristics, but are in line with the view that the characteristics do not converge over time. The evolution of an industry shows similarities with the empirical results as the model proposes a strong correlation of entries and exits in the markets, the development of product life cycles, and the observation of clustering of innovations in the technology space and over time.

At this point it should be mentioned that multiple assumptions of the model are also based on empirical regularities: For example the interpretation of knowledge and knowledge build-up in firms (Dosi, 1988a; Dosi et al., 2006), the interpretation of learning (Nooteboom et al., 2007; Wuyts et al., 2005), and the assumption that knowledge spillovers are local in terms of technological and geographical proximity (Jaffe et al., 1993; Audretsch and Feldman, 1996b; Dosi et al., 2006). Apparently, empirical regularities used for model assumptions cannot be used for model validation. Stylized facts - or theory that survived the empirical test - are therefore important as input factors while building the model as well as guidelines for the interpretation of model outcome. The next three sections will focus on the latter aspect.

Furthermore, the simulation model in this book is also confronted with theoretical models in order to underline the plausibility of the results. The model-to-model comparison during the process of model validation is called 'docking' (Kennedy et al., 2006). In Section 3.1 the model is compared to a game-theoretic model of

Alsleben (2005) and in Section 7.2 to a simulation model of Winter (1984).

5.2.1 Firm Size and Growth

As a first stylized fact the distribution of firm size, firm growth and the correlation of firm size and research and development activities should be highlighted. Many empirical studies indicate that firms differ in their size measured in terms of turnover, number of employees or market shares. Typically the empirically observed distribution is positively skewed showing many small and few large firms (Schmalensee, 1989; Sutton, 1997; Marsili, 2001). Within-industry firm differences are believed to be higher than between industries (Jensen and McGuckin, 1997). Dosi et al. (2006) propose the usage of rank size plot in order to evaluate the simulated outcome and show that the observations do not follow a log-normal distribution. We restrict our analysis to histograms which probably give a better impression of the distribution.

Figure 5.2 a) shows a histogram of the firm size for 100 simulation runs at the end of the simulated time horizon. In the picture the turnover of a firm is taken as a proxy for firm size. The distribution clearly indicates that most of the firms only reach a small size. Some of the firms manage to go beyond a threshold and reach a medium size whereas only very few firms are extraordinarily successful. Because the distribution has at least two peaks, it can hardly be approximated by a log-normal (similar to Dosi et al., 2006). These observations can be supported by the fact that in most simulation runs 2 out of 10 firms have a size much greater than the arithmetic mean, 2 to 3 firms are settled around the mean and 5 to 6 firms indicate a very low value even below the starting level. Therefore, we conclude that the outcome of the simulation studies concerning the distribution of firm size is in line with empirical findings.

Regarding firm growth rate distributions Dosi et al. (2006) argue that they are not Gaussian and can be well proxied by fat-tailed, tent-shaped densities in a Laplace distribution. The distribution of average firm growth rates (measured in percentage change of firm size) over the simulated periods are shown in Figure 5.2 b). The histogram shows a high peak around 5% growth per period. From the picture it is not obvious whether the observations can be well approximated by a Laplace density. Another reason against this kind of distribution could be seen in the asymmetry indicating a positively skewed distribution as shown in the figure.

Other authors find evidence that growth of firms diminishes with size (at decreasing rate) and decreases with age when firm size is held constant and that the average and variance of firm growth rates decline with the age of firms. Young firms have on average higher and more differentiated rates of growth (Geroski, 1995; Caves, 1998; Marsili, 2001). In the context of firm growth rates the simulation model departs

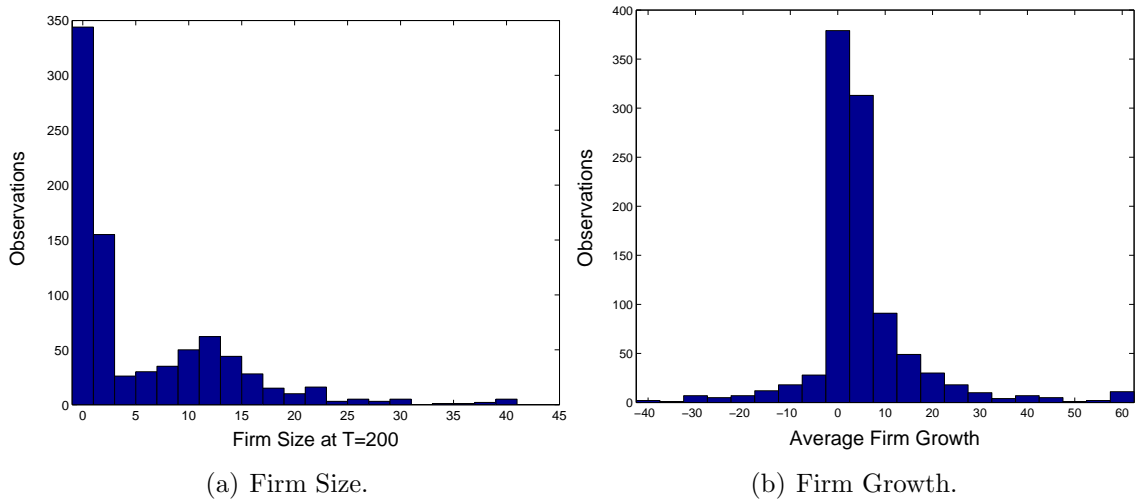


Figure 5.2: Histogram of firm size and firm growth in 100 simulation runs.

from the empirical studies. Here the growth rates of the 2 to 3 biggest firms out of 10 are stable whereas the smaller firms have only minor changes or even negative growth rates. The mean and the standard deviation of growth rates is not decreasing but increasing or remaining on a constant level, which does not result in higher and more differentiated growth rates of young firms. Therefore the observed growth patterns do not fit the industry evolution sketched in the cited surveys. The debate on Schumpeterian competition later in this chapter will add more details to this discussion.

Some empirical surveys study the relationship between firm size and R&D. They propose that R&D increases proportionately with size (thus indicating no advantages of firm size), that the number of innovations tends to increase less than proportionately with firm size, and that R&D productivity appears to decline with size (Cohen, 1995). Others formulate the proposition that small firms on average have higher rates of innovation than large firms (Caves, 1998; Acs and Audretsch, 1987, 1988), which is similar to a declining R&D productivity with size. The results of the simulation studies seem to be in line with these findings. For example with respect to product innovations the simulated outcome shows that the expenses for product innovations increase proportionally, the number of new products developed by a firm increase less than proportionally and the R&D efficiency measured in number of product innovations divided by investments decreases with the size of a firm. One reason for the first correlation is the fact that firms' profits increase in the simulated output with the size of the firms and, thus, the bigger firms invest by assumption more in product innovations.

5.2.2 Persistence of Firm and Industry Characteristics

The second topic, that many empirical researchers are interested in, runs under the heading of persistence. Many characteristics of industries and firms are believed to be quite stable over time. Profitability differences among firms (Schmalensee, 1989; Geroski, 1995; Marsili, 2001) as well as inter-industry differences in profit rates (Geroski, 1995; Marsili, 2001) tend to persist for long periods. Market concentration is relatively stable in an industry but there is a high degree of market turbulence (entry and exits, change of market shares) (Marsili, 2001). The same accounts for the size distribution of firms (Caves, 1998). Regarding firm performance given by inter-firm productivity differentials authors find that they are significant and quite lasting (Bartelsman and Doms, 2000; Dosi et al., 2006). Jensen and McGuckin (1997) argue that plants (or firms) have stable permanent differences in costs that are reflected in their product prices, even within narrowly defined product groupings. A recent empirical study of panel data of German manufacturing and service firms during the period 1994 - 2002 indicates that innovation input and output is persistent to a very large extent at the firm level (Peters, 2005).

In this context the simulation results are examined in terms of persistence of market concentration, profit rates, productivity differences as well as investments in and number of product innovations. Starting with the evolution of average market concentration at the sub-market level the simulations depart from the empirical patterns. A very robust result of the simulation exercises shows that average market concentration is not stable but increasing over time, although one must add that at the end of the simulated time horizon it stabilizes at a high level. This finding fits the picture of the distribution of firm size since it becomes clear that at most 2 to 3 out of 10 firms seem to dominate the industry as the simulation continues. The outcome of an increasing market concentration fits the empirical result of Caves (1998) and Sutton (1998), who found that concentration tends to increase in vertically and horizontally differentiated industries.

Looking at the firm level data the results of the simulations get closer to the empirical regularities. The differences in profits of the firms emerge very soon and they do not converge. As in the case of firm size the variance of the distribution of firm profitability increases over time showing an increasing difference. In order to get an idea of the development of firm productivity differences Figure 5.3 shows the evolution of average knowledge for process innovations ($RD_{i,j,t}^{proc}$) which determines the cost and productivity of firms in the model. Three graphs are shown: The average productivity of the firm which happens to be in period t at the first (Rank 1, dotted line), medium (Rank 5, dashed line) or the lowest rank (Rank 10, solid line). Again all graphs show averages over 100 simulation runs.

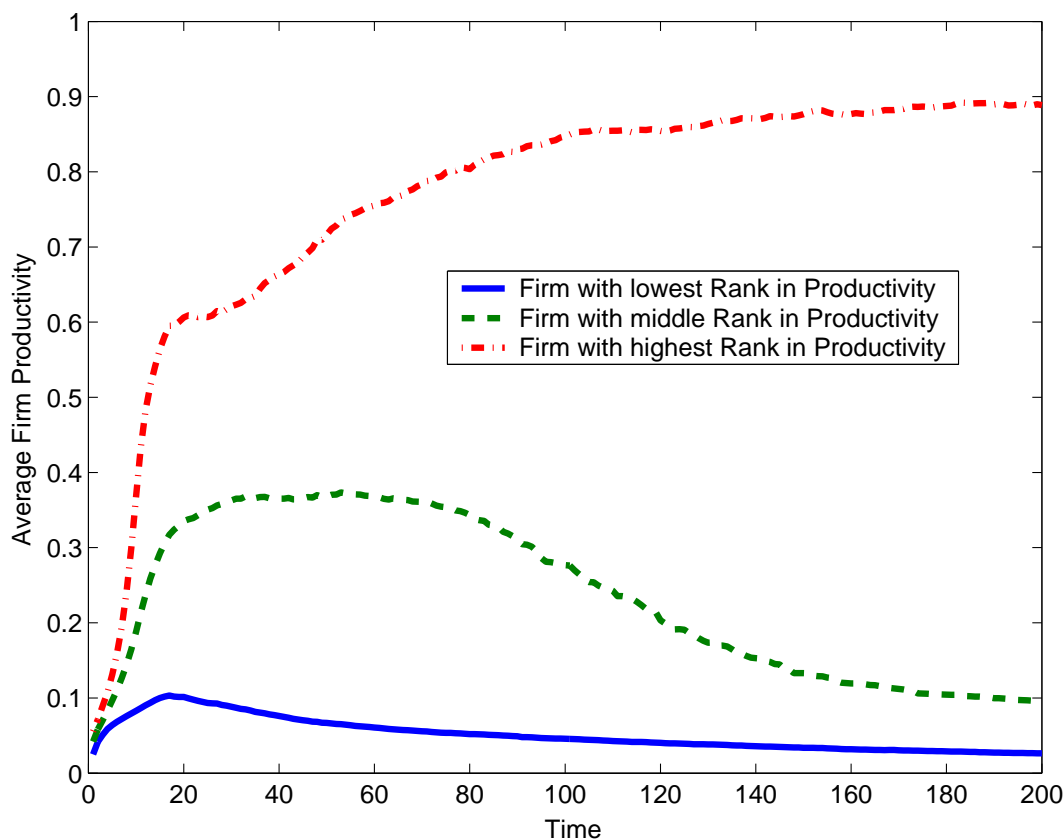


Figure 5.3: Evolution of firm productivity differences.

The figure shows that the least productive firm can only increase its average productivity at the beginning but afterward the level decreases or stabilizes at a very low level. The best firm manages to increase its average knowledge for process innovation very fast and then the value is still increasing but at a lower rate. The difference between the best and the worst firm is thus increasing over time. The third graph shows the development for a firm with medium levels of productivity. During the first half of the simulation the line for this firm is located in the middle between the best and the worst firm. But at a certain time the medium firm cannot keep its standard and its productivity approaches the line of the firm with the lowest productivity. One reason for this is the fact that the more successful firms keep on introducing new product innovations which increase the number of relevant technologies, such that even with constant knowledge the average values of the medium firm decline. In conclusion one can say that the differences in productivity at the firm level are persistent over time and that the difference in productivity between the few very successful and the other firms even increases as the simulation continues.

Further analysis of the simulated outcome shows that the differences in innovation input (measured in investments in process and product innovations) are also

persistent over time. After an initial phase the expenses for innovations remain on a constant level for the majority of the firms. Only the best or second-best firm can further increase the amount of investments in innovation. Since process innovation results were already mentioned, the innovation output in the form of successful product innovation indicates a strong separation between leading and lagging firms. Approximately only half of the firms introduce new products after a given time period. Thereafter, the number of new product innovations increases strongly with the ranked firm.

Altogether the study of the simulation outcome leads to the conclusion that differences between firms are not only persistent but increasing. This holds for firms' market shares, profitability, innovation input and innovation output.

5.2.3 Schumpeterian Competition

The view of Schumpeter on competition incorporated a dynamic and active picture in the way that more productive firms grow and lead industry growth at the expense of less efficient rivals (Schumpeter, 1912; Nelson and Winter, 1982). The technical change pushes the laggards and non-adopters farther back whereas the technologically leading firms survive and grow in the competitive selection process based on innovations. Economic growth is achieved via a competitive selection process in which the most efficient firms survive (Jensen and McGuckin, 1997; Caves, 1998). This interpretation of competition seems to find some empirical support. Two-thirds of the aggregate productivity growth is attributable to gains in market shares by most efficient producers and declines in market share by the least efficient Jensen and McGuckin (1997). Following the arguments of the last two sections one can say that the simulated outcome is in line with these findings. The industry shows a strong separation between successful firms, which have high market shares, earn higher profits and conduct more innovations, and firms with shrinking market shares, profits and average knowledge. The separation between firms is not only persistent but increasing over time. Figure 5.3 underlines this result: The distance between the technological frontier given by the most successful firm and a firm with medium rank or lowest rank is increasing. Firms that were successful in the past are much more likely to be successful in the future, which was described as 'success breeds success' by Malerba and Orsenigo (2000). Of course this result is also driven by the structure of the model, which is evolutionary by assumption.

Concerning entry and exit of firms two different strands of the literature can be identified: Argumentation based on the concept of entry barriers going back to Bain (1956) and industry life cycles (see e.g. Klepper, 1996). In the model the total number of firms in the industry n is assumed to stay constant and entry in

the industry is only possible if a firm is corrupt and is replaced by another firm. A strategic behavior of firms in- and outside the industry about industry entry and exit is not incorporated. But entry and exit in the different sub-markets of the industry is modeled and the market structure on these sub-markets emerges endogenously. Hence, this section concentrates on the entry and exit and the resulting market structure in markets, but not in industries.

Traditionally entry barriers (scale economies, capital requirements, advertising intensity or innovations) are estimated to be high (Geroski, 1995). They are believed to be positively correlated with firm profitability and reduce the number of entrants (Bain, 1956; Schmalensee, 1989; Caves, 1998). But the picture is not that clear since other authors find that the level of profitability in an industry seems to have a rather limited effect on the rate of entry. Additionally entry rates are still relatively high in concentrated markets and rather random across industries (Marsili, 2001). Entry barriers seem to have less influence on entry by initially large newcomers, by firms established in other industries, or by multinational firms (Caves, 1998). Hence Marsili (2001) concludes that entry barriers seem to be quite ineffective as deterrents to entry. In this model incumbents do not have the possibility to strategically use their knowledge and market power to prevent firms from penetrating their markets.⁵ But in general the entrants have less knowledge of process innovations, which results in higher production cost⁶. After the initial periods following a successful product innovation entry is quite easy but entrants have to catch up on the technological leader in order to gain similar profits. The simulations demonstrate that there are entries over the whole time horizon and the number of entrants is particularly higher in the early periods after founding. The potential knowledge lead of the incumbents does therefore not deter entry in the model. One aspect most researchers agree upon is the fact that entry and exit rates in industries are highly positively correlated and that entrants suffer from high rates of infant mortality (Geroski, 1995; Caves, 1998; Marsili, 2001). Indeed the entry and exit rates in the sub-markets of the simulation runs are strongly correlated indicating a correlation coefficient of 0.75 and higher. This number is indeed similar to real-world data like the result of Baldwin and Gorecki (1991), who find a correlation between exit and entry in the interval between 0.5 and 0.7 for Canada during the 1970s, or the study of Dutch retailing Carree and Thurik (1996), who show a correlation of 0.78 per year during 1981-1988. Furthermore, one can observe in the simulated data that most entrants leave the market since they are not able to make positive profits.

Another interesting empirical result is given by Geroski (1995), who explains that high rates of entry are often associated with high rates of innovation and increases

⁵See the literature about price wars and R&D races, e.g. Reinganum (1983); Dixit (1988).

⁶See equation (4.2).

in efficiency not only by the entrants but also more innovations by the incumbents as a reaction to the entry and that *de novo* entry is more common but less successful than entry by diversification. Chapter 6 will have a closer look at firm strategies and diversification. Caves (1998) sees the reason behind changes in the market structure in the basic features of an industry's technology and demand conditions. Similar to this is the point made by Cohen (1995) when he mentions that once one controls for firm size, the effect of market concentration on innovation activity is relatively slight and appears to reflect the effect of other industry characteristics. The debate of industry characteristics and the notion of technological regimes will be the topic of Section 7.2.

The industry or product life cycle approach describes the evolution of a product after its innovation in four subsequent stages: Introduction, expansion, consolidation, and contraction. At the beginning of the industry, the number of entrants rises over time or it may attain a peak at the start of the industry and then declines over time. Despite the market growth entry slows down and exits overtake entry rates, which results in a shakeout of active producers in the industry. Initially the market shares of the largest firms decline but later on they stabilize over time. The rate of product innovations and the number of competing product versions decline whereas the firms employ more effort on reducing production cost. See e.g. Geroski (1995); Klepper (1996); Caves (1998); van Dijk (2002) for a more detailed description of product life cycles. These regularities have been widely confirmed by empirical studies for such different industries as automobiles, car tires, televisions, penicillin, and typewriters (Klepper and Simons, 2005). Explanations of the industry life cycle patterns were based on the emergence of a dominant design (Utterback and Abernathy, 1975; Abernathy and Utterback, 1978) or the characteristics of innovative firms (Klepper, 1996).

The number of firms in each sub-market can be evaluated in the simulation model. Figure 5.4 shows the number of active firms in the market which was established by the first product innovation. The graph shows the average number of firms with positive output on this market over 100 simulations. After the founding of the market many firms enter the new market but the number of firms is decreasing in time and seems to stabilize as the simulations continue. The same holds for profits: At the beginning the profits are high and later decline to constant level. A similar evolution regarding the number of firms can be observed for every new sub-market which is founded through a successful product innovation. By assumption the firms invest first in product innovations in order to introduce a new product variant and then in process innovations to reduce production cost. Altogether the simulations more or less reproduce the pattern of product life cycles on the level of sub-markets but the result for the positive correlation between entries and exits is more evident.

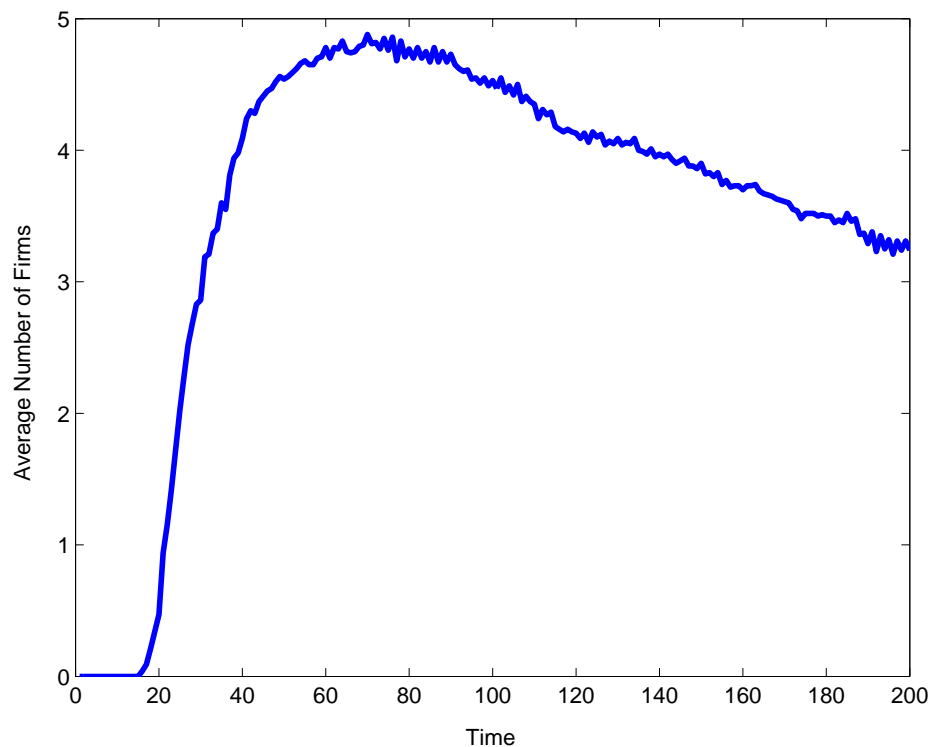


Figure 5.4: The average number of active firms in the market founded by the first successful product innovation.

A last empirical stylized fact considers the location and timing of innovations. It was argued that innovations cluster in time and space (Schumpeter, 1939; Silverberg and Verspagen, 2003). This behavior of the model could be observed as there are times of no new product variants followed by times of many successful product innovations in close technological distance. A possible explanation could lie in the learning externalities between firms which allows several firms to simultaneously achieve high knowledge in a particular technological area. Once this knowledge exceeds a certain threshold, every firm has a rising probability to successfully implement a new product innovation. The same effect arises if a firm is able to benefit from internal knowledge spillovers, which lead to a clustering of product innovations of that firm.

After this general comparison of the simulated data with observed empirical regularities as part of the model validation we continue in the next chapters with a deeper analysis of the main mechanisms of the model. Whenever there are relevant empirical studies, we mention them at the respective text passage. We start with a look at firm strategy.

Part III

Applications

Chapter 6

Firm Strategy

If we accept the assumptions and relevance of the model proposed in the previous chapters, we can apply the theoretical model to different questions and problems. We start by an investigation of firm strategy in the context of proximity and innovation. We try to show which strategies in this particular setting seem to be profitable and what trade-offs and challenges managers should be aware of. We do this by examining firm-specific parameters in a regression analysis and by discussing different scenarios which help to identify the influence of geographical and technological proximity on competition between firms.

6.1 Firm Strategy and Proximity

A precondition to investigate the issue of firm strategy is heterogeneity of behavior and capabilities. Additionally, empirical evidence shows that firm differences are given in reality and that they have a major impact on economic variables (Nelson, 1991). As argued in Section 3.3 one strength of the agent-based approach is the modeling of heterogeneous agents, e.g. firms, which interact in a complex environment. Here, the firms compete mostly through innovations which are the result of accumulated knowledge, capabilities to perform R&D, and of course their operational routines. The analysis of firm strategy is done on a firm and aggregated level to assess the consequences for the firm and the industry. The environment for firm interaction is captured in the term of proximity.

In this work firm strategy can be evaluated in terms of geographical and technological proximity. The main trade-off for each firm when choosing the geographical location either at the core or on the periphery is given by the possible positive learning effects versus the possible loss of economically valuable knowledge in the agglomeration. Since the firms are direct competitors on the horizontally differentiated markets, the link from knowledge to economically valuable knowledge can be established. The knowledge assets of the firm and its competitors imply which

firms succeed and which do not. The amount and structure of knowledge is related to technological proximity. Additionally the model considers other elements of firm strategy such as the attitude toward market entry, market exit and investments in R&D. This kind of firm behavior is captured in the model and can be analyzed.

The measurement of geographical proximity is rather simple in the model. Geographical proximity is given by the choice of the location (either core ($d_{i,t}^{geo} = 0$) or periphery ($d_{i,t}^{geo} = 1$)) and the number of firms in the agglomeration gives the aggregated outcome for geographical proximity. The case with technological proximity is more complex since the area and amount of knowledge of a firm or an industry have to be captured somehow. One possible way to do this is connected with the notion of **specialization**. There are two dimensions of specialization in this context, namely the distribution of the locations of the technologies employed in the firm and the variance in the amount of knowledge firms have with respect to different technologies. Hence, the following two properties make a firm or an industry 'specialized': First, the technologies associated with the active sub-markets are clustered (in one or several clusters) rather than being evenly distributed in the technology space. Second, there is a significant variance in the stock of technology-specific knowledge across active sub-markets with accentuated peaks at certain technologies. Figure 6.1 shows the different types of specialization which describe the technological location and height in the model. An industry, a firm or the firms in a location can be diversified (a), specialized in location (b), specialized in height (c) or specialized in location and height (d).

In order to capture these different aspects of specialization, as introduced in Dawid and Wersching (2006), two different versions of a specialization index are constructed where both are transformations of the Hirschmann-Herfindahl-Index which has been used in past empirical (Henderson et al., 1995) or simulation (Jonard and Yildizoglu, 1998) work dealing with specialization. To be able to compare degrees of specialization across different settings with different numbers of existing variants the Hirschmann-Herfindahl-Index is normalized in such a manner that it always has the range $[0, 1]$. In particular we use the index

$$SPECIALIZATION_t = \left[\frac{\sum_{j=1}^N a_{j,t}^2}{(\sum_{j=1}^N a_{j,t})^2} - 1/N \right] \cdot \frac{1}{1 - 1/N}, \quad (6.1)$$

where N is the number of technologies actively used and the interpretation of $a_{j,t}$ depends on which type of specialization is considered. In order to capture the degree of clustering of technologies employed in the population we set $a_{j,t} = d_{j,j+1,t}^{tech}$,

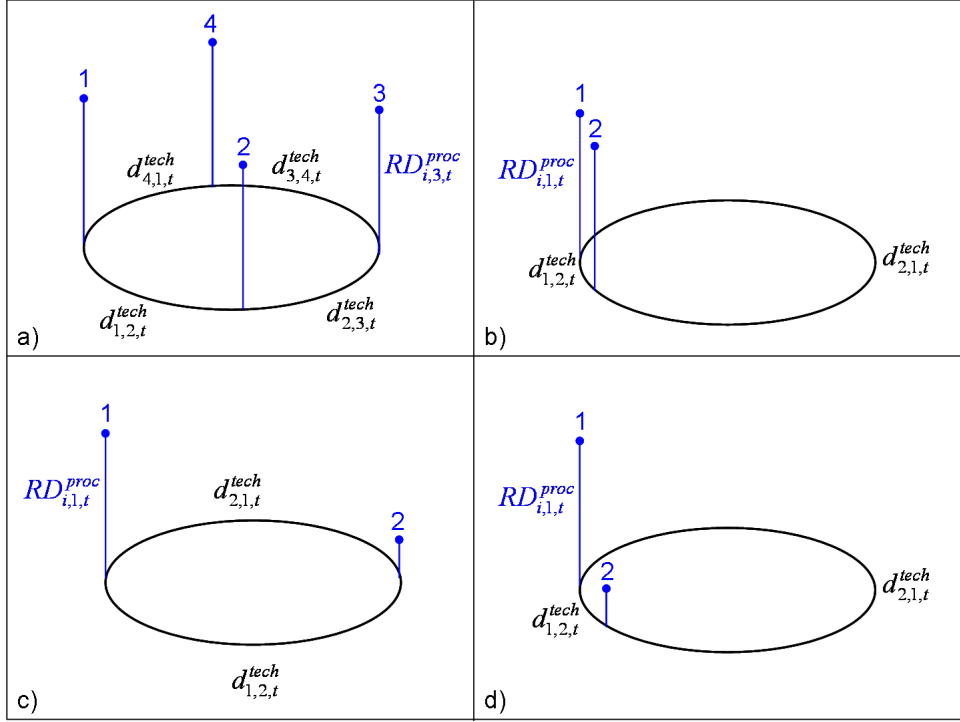


Figure 6.1: Types of technological specialization: a) no specialization, b) specialized in location, c) specialized in height and d) specialized in location and height.

which gives the distance between technology j and the clockwise seen next active technology in the circular technology space. In order to capture specialization in knowledge stock we set $a_{j,t} = \max_{i=1,\dots,F} RD_{i,j,t}$, where $RD_{i,j,t}$ denotes the stock of knowledge specific for technology j firm i has at time t . An aggregated index, which represents the total specialization, is the arithmetical mean of these two indices. But it could be argued that the index for specialization in technological location is more relevant because the demand for products and the degree of knowledge spillovers is more influenced by the technological distance than by the height of the knowledge stocks.

With the indices for specialization it is possible to describe and investigate several aspects of technological proximity. For example the proportions of specialized and diversified firms could be studied. Breschi et al. (2003) introduce an empirical study on firms from the United States, Italy, France, UK, Germany, and Japan and specialization is measured based on patent data from the European Patent Office from 1982 to 1993. If a firm took patents from more than one technological field, it was labeled as diversified innovator. If a firm took at least one patent but only in one technological field, it was called a specialized innovator. In their sample the authors estimated that 69.8 % of the innovative firms were specialized and 30.2 % diversified. The interpretation of technology fields in Breschi et al. (2003) is very broad and could be compared to the interpretation of an industry in this work. Thus

the firms in the model belong to one technology field by assumption. But if we accept the view that the firms are technologically specialized within the industry, and this should be the case with an index from equation (6.1) greater than 0.5, then a computation of the proportions is possible. At the end of the simulation runs in the standard scenario approximately half of the firms have an aggregated index equal or greater than 0.5. Interestingly, if we consider only the index for specialization in technological distances, approximately 62 % of the firms are more specialized. This value comes quite close to the empirical evidence of the patent sample. With the potential to measure the technological and geographical proximity, we can now start to study the impact of firm strategy on the economic performance of firms and the outcome of geographical and technological location.

As a first analysis we perform a multiple linear regression analysis of the randomly chosen strategy parameters on the outcome for aggregated profits over all periods in the standard scenario of the industry. The regression analysis considers parameters from the two equations for evaluating market choice (see equation (4.17)) and location (see equation (4.30)), different inertia parameters and the height of investments in research activities of the firm. For the regression 200 runs are considered, which results in 2000 data points with 10 firms in each iteration. The statistical results are given in Table 6.1. Although the considered parameters are only able to explain about 24% of the original variability, some striking results can be identified.

$\sum_t \Pi_{i,t}$	Coef.	Std. Err.	t	$P > t $
$\delta_{i,\Pi}$	56.06***	16.87	3.32	0.001
$\delta_{i,SP}$	-13.68	17.14	-0.80	0.425
$\delta_{i,RD}$	-0.91	16.69	-0.05	0.956
$\delta_{i,T}$	-93.31***	16.80	-5.55	0.000
$\kappa_{i,en}$	-378.85***	16.16	-23.45	0.000
$\kappa_{i,ex}$	1096.00***	166.91	6.57	0.000
$\kappa_{i,S}$	13.35	17.04	0.78	0.434
q_i^{prod}	176.54	214.54	0.82	0.411
q_i^{proc}	649.72***	210.51	3.09	0.002
Const.	172.26**	69.01	2.50	0.013

Table 6.1: Multiple linear regression results of strategy parameters on firm profits (Observations= 2000, $R^2 = 0.2440$).

The parameters $\delta_{i,\Pi}$ and $\delta_{i,T}$ are significant and have a positive respectively negative coefficient. Both parameters are used in equation (4.17) to choose market entry candidates or to choose an attractive area for product innovation. The inertia parameters for market entry and exit ($\kappa_{i,en}$ and $\kappa_{i,ex}$) turn out to be highly significant. Apart from the constant term, the amount of profit which is invested in process innovations (q_i^{proc}) is significant and positively correlated with the profits of this firm.

A first important result shows that the parameters which change the technological location of the firm ($\delta_{i,\Pi}$ and $\delta_{i,T}$) seem to be significant whereas all parameters which determine geographical location ($\delta_{i,SP}$, $\delta_{i,RD}$ and $\kappa_{i,S}$) do not have a significant influence on the level of aggregated profits of a firm. The signs of the coefficients concerning technological proximity indicate that the higher a firm weights potential profits in a market compared to technological focus the more profitable is the firm. This can be concluded because there is a positive influence of $\delta_{i,\Pi}$ and a negative influence of $\delta_{i,T}$ on profits. It should be added that the value of the coefficient is rather small compared e.g. to the coefficient of the significant inertia parameters for market entry and exit, which are also chosen from the interval $[0,1]$. Section 6.3 will examine whether this result is general or emerges only in specific scenarios. The non-significant result for geographical proximity is at this point rather surprising and requires further analysis, which is done in Section 6.2.

Another interesting finding can be seen in the fact that the more likely a firm enters into a new market and the longer a firm stays in a market (even with losses), the more profitable is this firm. The first effect comes from the significant and negative coefficient of $\kappa_{i,en}$, and the second effect from the significant and positive coefficient of $\kappa_{i,ex}$. Following this outcome firms benefit from serving as many markets as possible although there are assumed fixed costs. Firms that stick to their markets and are able to bear more negative profits prove to be more economically successful in the regression.

Concerning the expenditures for R&D a differentiation between process and product innovations is necessary. The more a firm invests in cost-reducing process innovations, the higher are the economic profits. Although both coefficients are positive, only the height of investments in product innovations appears to have a significant influence. One reason for this result could be that process innovations for sure reduce cost while product innovations always include an element of uncertainty so that their benefits do not arise automatically.

Apart from the analysis with fixed and constant intervals for the firm-specific parameters, the further sections examine the outcome for different scenarios. The next section starts with a closer look at the geographical location decisions of the firms.

6.2 The Incentive to Agglomerate

Whereas the previous section does not give a clear relation between geographical location decisions on the profitability of firms, this section will deepen the analysis on geographical proximity. In the model firms face the trade-off between gaining or losing knowledge through local learning. On the one hand, firms can learn in close

geographical proximity to competitors and thus improve their knowledge for process and product innovations. On the other hand, firms are assumed not to be able to prevent knowledge from spilling over. A competitive advantage can be lost through imitation by competitors. These effects are the only relevant strategic elements of the geographical location decision in the standard case.

Another possible effect may arise through costs of scarce resources (e.g. labor or land), if many firms agglomerate in a particular location.¹ For the discussion of geographical proximity we therefore extend the standard model such that production cost may rise with the number of firms in the agglomeration. We call this scenario 'Additional Cost in Core'. Hence, equation (4.2) in this setting is replaced with the following:

$$c_{i,j,t} = c^{ini} [c^{min} + (1 - c^{min})(1 - RD_{i,j,t}^{proc})] + (1 - d_{i,t}^{geo}) \cdot (|N_t| - 1) \cdot R. \quad (6.2)$$

The last term $(1 - d_{i,t}^{geo}) \cdot (|N_t| - 1) \cdot R$ in equation (6.2) is added to the previous formula. Here the costs at the core are only considered if a firm is in the agglomeration ($d_{i,t}^{geo} = 0$). The costs of the scarce resource depend on the number of firms at the core, which is given by $|N_t|$, and the factor R , which stands for the increase of costs through every additional firm in the agglomeration and is set to $R = 0.15$. Note that if a firm is alone at the core ($|N_t| = 1$), there are no additional congestion costs. In this scenario the de-agglomeration force of congestion cost has to be included in the evaluation function for the geographical location of the firms.

Therefore, equation (4.30) is altered as follows:

$$\begin{aligned} v_{i,t}^{geo} = & \left[\mathbb{E} \left(\frac{RD_{i,j,t}^{proc}}{RD_{j,t}^{proc}} \right) \right]^{\frac{\delta_{i,RD}}{\delta_{i,RD} + \delta_{i,SP} + \delta_{i,R}}} \\ & \cdot \left[\mathbb{E} \left(\frac{SP_{i,j,t}^{proc}(d_{i,j,t}^{geo} = 1)}{SP_{i,j,t}^{proc}(d_{i,j,t}^{geo} = 0)} \right) \right]^{\frac{\delta_{i,SP}}{\delta_{i,RD} + \delta_{i,SP} + \delta_{i,R}}} \\ & \cdot \left[1 - \mathbb{E} \left(\frac{c_{i,j,t}(d_{i,t}^{geo} = 1)}{c_{i,j,t}(d_{i,t}^{geo} = 0)} \right) \right]^{\frac{\delta_{i,R}}{\delta_{i,RD} + \delta_{i,SP} + \delta_{i,R}}} \end{aligned} \quad (6.3)$$

Now equation (6.3) considers three possible effects. A weight parameter $\delta_{i,R} \in [0, 1]$ for the relation between production cost outside and inside the cluster is incorporated in the formula. This parameter represents the firm strategy concerning congestion costs. A high value compared to $\delta_{i,RD}$ and $\delta_{i,SP}$ indicates that a firm will react very sensitively to the rise of production cost when many firms agglomerate at the core.

¹For example Glaeser (1998) debates congestion forces at a city level.

The outcome regarding geographical proximity over time in the standard scenario (solid line) and the extension discussed above (dashed line) is shown in Figure 6.2.² The curves show a similar pattern with a peak after the initialization of the simulation. Afterward the number of firms at the core slightly decreases to a level of 5 out of 10 firms in the agglomeration for the standard case. The graph which includes an additional de-agglomeration force in the form of congestion cost decreases after the initial maximum with fewer oscillations to a lower level. All curves show the result of 100 simulation runs. The difference between the two scenarios is highly significant, see Appendix A.3.

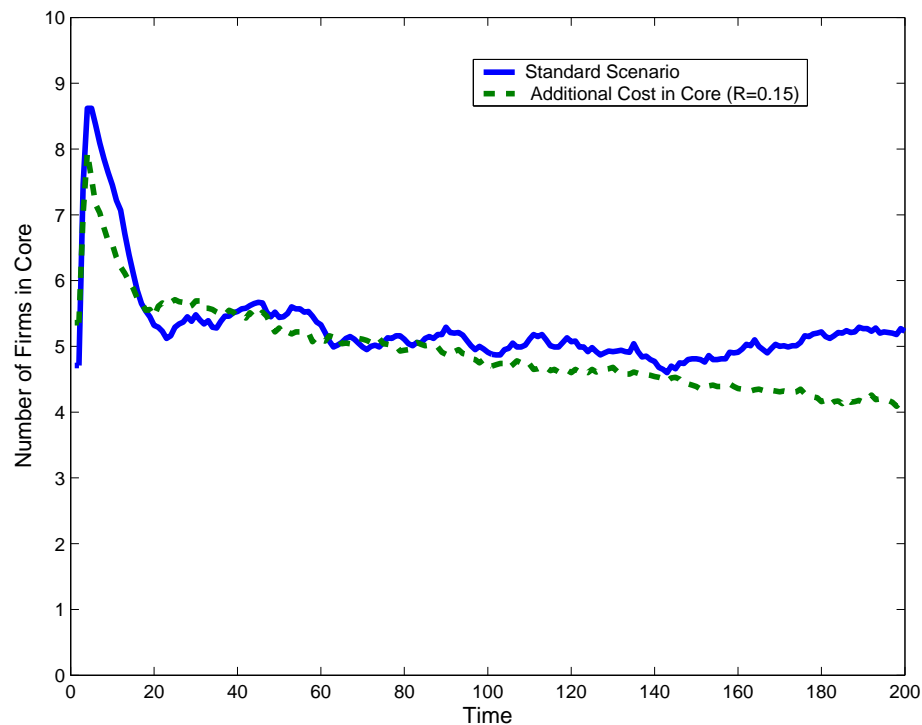


Figure 6.2: Average number of firms at the core with and without congestion cost.

The initial location was chosen randomly and thus on average five firms start at the core. The firms start with knowledge in only one technology. By assumption two firms have a knowledge stock greater than zero in each technology and hence no firm has a huge technological lead. As the knowledge for process innovations at start is quite low, in the extension the additional costs at the core compared to other costs are also relatively low. Because of this, firms have a strong incentive to join the core at the beginning of the simulations. This incentive is reduced, in particular, after the first introduction of new products around period 20. With successful product innovations the innovating firms become technological leaders and try to keep their

²Like in Wersching (2007a) the standard and the additional cost at the core scenario are compared with each other. The results are quite similar although some of the model elements differ, see Chapter 4 for more details.

status by leaving the core. This explains the characteristic peak in all simulated scenarios and it becomes obvious that it emerges due to initial conditions. Further discussion will concentrate on the more general pattern in later periods.

In Figure 6.2 two different cases are presented: No and high additional costs for scarce resources at the core. It can be seen that even with no extra cost not all firms join core. The possible threat of knowledge losses through knowledge spillover is hereby the reason for voluntary isolation. In case of high costs for the scarce resource these costs are approximately equal to the average initial cost when half of the firms locate at the core. This means that a location at the core rises the variable costs for every product quantity in that height. Because of process innovations the relative value even increases. As illustrated in the picture even with these high additional costs most firms - at least in the first half - choose a location at a small geographical distance to their competitors. Despite the differences in the two scenarios the overall resulting effect shows that a low geographical distance to competitors is important during a phase of very heterogeneous knowledge, e.g. during the developing period of an industry, as well when the industry becomes more mature.

The graphs appear to differ in their gradient where in the standard scenario the number of firms at the core is higher than in the scenario with congestion costs. In order to see if the difference persists or is only an artifact of the considered time horizon we extend the simulated number of periods to 500. Figure 6.3 shows the outcome for the two scenarios in the long run. The picture shows the result of 50 iterations of the standard scenarios and 10 iterations of the scenario with additional costs at the core. As it was not clear whether the curve in the standard scenario is oscillating or decreasing, we perform a long-run simulation over 50 runs.³ All additional simulation exercises indicate that even in the standard scenario the incentive for geographical proximity is reduced over time, which was not obvious from the previous picture 6.2.

In Figure 6.3 the development of the number of firms in the agglomeration over a long time horizon is presented. Both curves are fitted with a linear trend in order to get an idea of the general development. In a linear regression analysis the coefficient of a time variable proves to be very significant and has a negative influence on the number of firms at the core.⁴ The linear trend curves support the first impression that the incentive for core in both scenarios is reduced over time and the decline is greater with additional congestion cost.

In the evaluation function for the geographical location in equations (4.30) and

³The number of iterations was limited by time restrictions, e.g. the simulation of 50 runs over 500 periods had a computational time of about 10 days.

⁴In the standard scenario the statistics are: $R^2 = 0.195$ and the t-value for the coefficient of the time variable is $-10,999$. The extended version of the model performs a little better with the corresponding values $R^2 = 0.407$ and a t-value of $-18,498$.

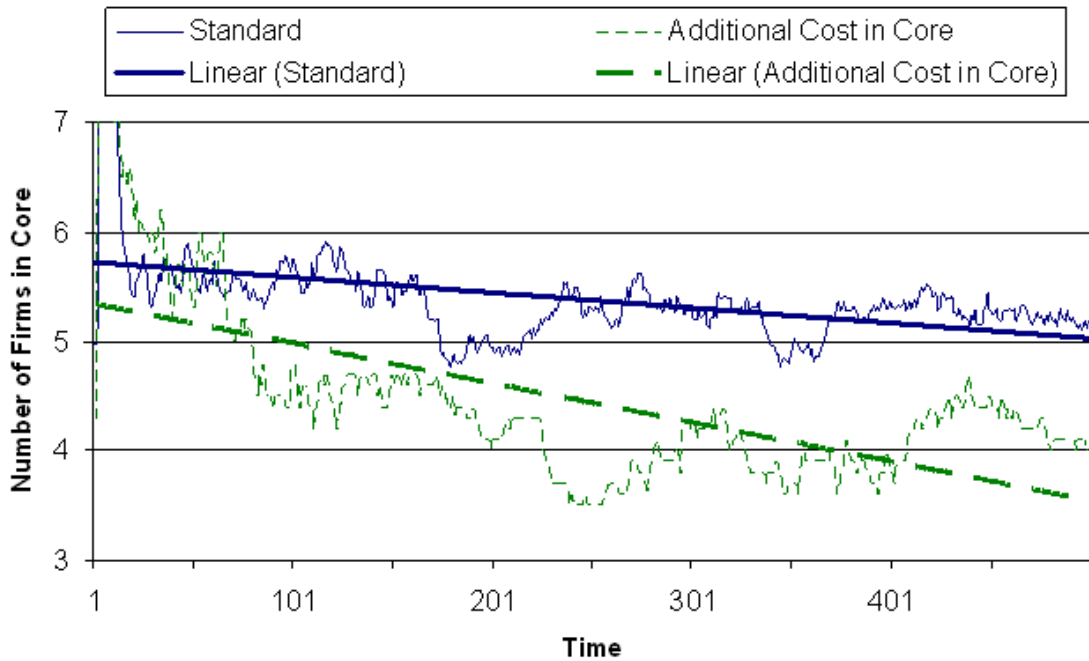


Figure 6.3: Average number of firms at the core with and without congestion cost in the long run.

(6.3) two respectively three factors are considered: The firm's own advances in knowledge for process innovations, possible learning gains through knowledge spillovers at the core and in the extension the costs for scarce resources at the core. Over time the evaluations of the single factors change and at least the first two work against each other. At the beginning knowledge between firms is quite heterogeneous, which results in single firms having high knowledge in a few technologies. Because of this in earlier periods the evaluation for knowledge strongly points toward a location on the periphery. As the industry evolves, the values decline but at a low rate. The situation with knowledge spillovers is exactly opposite. The heterogeneous knowledge at start creates a lot of learning possibilities for the firms in the agglomeration. Over time the fraction between internal and the total sum of internal and external spillovers increases and this makes a location at the core less attractive. The additional cost for all firms at the core in the extension of the standard model works also against core and the influence of the evaluation of congestion costs increases with the number of firms in the agglomeration.

A first explanation for the decline of firms at the core could lie in the upper limit for process innovations. But the technology space is still increasing with new product innovations, so that new learning possibilities at the core arise. In our view this mechanism does not drive the result. We are convinced that the attractiveness of a geographical location at the core decreases mostly because of reduced evaluation

values for knowledge spillovers. This effect is stronger than the opposing effect given due to reduced knowledge leads. Firms are initially attracted by high knowledge spillovers from other firms to join core, but as learning takes place firms in the cluster become more similar in their technological profile and the learning effect is reduced. Here the reason for a reduced incentive to agglomerate in a mature industry is seen mostly in lower learning possibilities through knowledge spillover: Firms at the core have *too similar* and the potential entrants have *too different* knowledge to benefit from agglomerating. In our understanding the assumption of a hump-shaped learning function for knowledge spillovers given by equation (4.10) drives this result. Internal knowledge spillovers within each firm become more important than external knowledge spillovers as the industry evolves. Hence, firms at the core leave and firms on the periphery do not enter the agglomeration.

The described outcome is similar to the empirical findings of Audretsch and Feldman (1996a), who show that agglomeration tendencies are stronger in the early stages of the industry life cycle. In their empirical investigation the authors used a data base that includes innovative activities for states and industries of the United States. The authors see empirical evidence for the propensity for innovative activity being shaped by the stage of the industry life cycle. Clustering of innovative activity is found especially in early stages of the industry life cycle and a dispersion of innovative activity takes place during the mature and declining stages of the life cycle. But in contrast to their conclusion this model does not suggest a decreasing role of tacit knowledge. Here the reduced possibilities for learning through knowledge spillover within and between cluster firms and potential entrants work against agglomeration in a mature industry.⁵

In order to shed more light on the changing role of knowledge spillovers we draw the total sum of internal and external knowledge spillovers over a long simulated period in Figure 6.4. All curves stand for mean values over 50 runs. There is an important difference in the evaluation of knowledge spillovers for the location decision and the curves in this picture because here realized external spillovers are presented and the evaluation is based on potential external spillovers. But the arguments for the choice of the location are supported because both potential and realized external knowledge spillovers lose relevance in comparison to internal knowledge spillovers.

The development of the graphs and statistical tests suggests that at the beginning firms learn mostly through external knowledge spillovers from competitors and as the industry evolves internal learning within the firms gets more important, see also Appendix A.3. Thus, the main source for new knowledge, apart from the firms' own

⁵Another empirical work by Dumais et al. (2002) debates the evolution of geographic concentration in the USA. The authors show that new firms and expansions of existing companies have a de-agglomerating effect whereas plant closures reinforce concentration levels. However, our model is not able to investigate those issues.

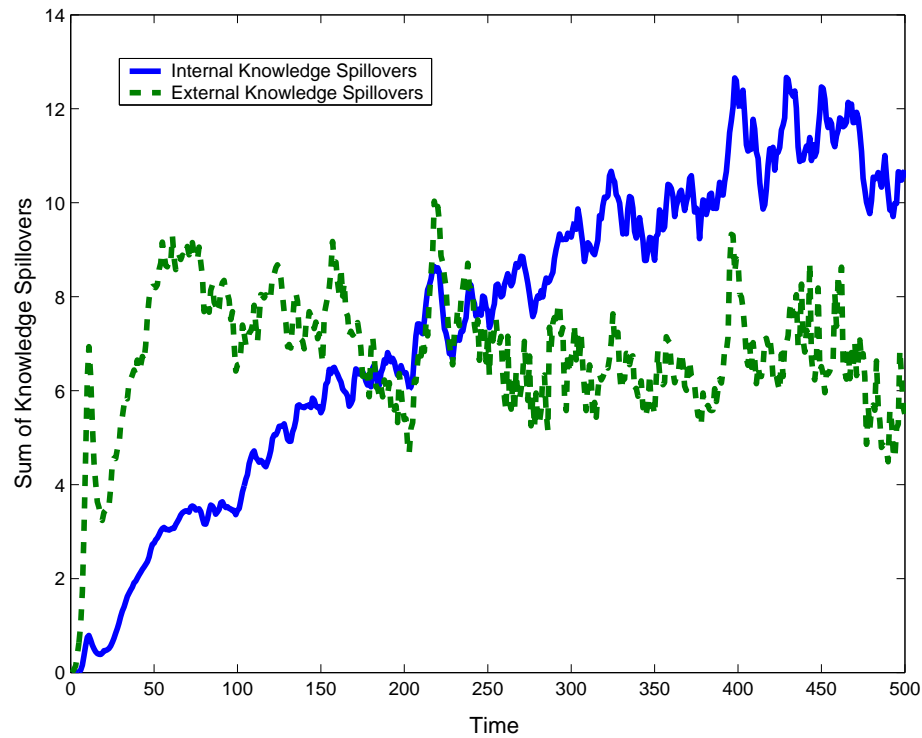


Figure 6.4: Internal and external knowledge spillovers in the long run in the standard scenario.

investments in R&D, changes over the industry life cycle from external to internal learning. This mostly emerges due to the rising relevance of internal knowledge transfers. The changing role of knowledge spillovers has to be seen in the context with the falling number of firms at the core. As fewer firms are attracted to the agglomeration or the knowledge of firms in the cluster gets more equal, the benefits of knowledge spillovers decline. It is a self-reinforcing process because lower learning possibilities make a location in close geographical proximity less attractive, which again reduces the incentive for core. Over time mostly the successful firms rely more on their own knowledge competencies given through internal knowledge spillover. The question emerges why the decline in the number of firms is not that strong. We will see in Section 6.3 that cluster firms are bound to the agglomeration because of their dependence on external knowledge spillovers even if the learning possibilities are very limited.

Another point worth looking at in the context of geographical proximity is the scale of possible knowledge spillovers and its impact on the incentive to agglomerate, as authors like Maskell and Malmberg (1999) emphasize the role of localized learning. The outcome of the model when varying the degree of knowledge spillovers is presented in Figure 6.5. Here three different scenarios are analyzed: The standard scenario and a case where all knowledge spillovers are doubled ('High Knowledge

Spillovers') or cut in half ('Low Knowledge Spillover').

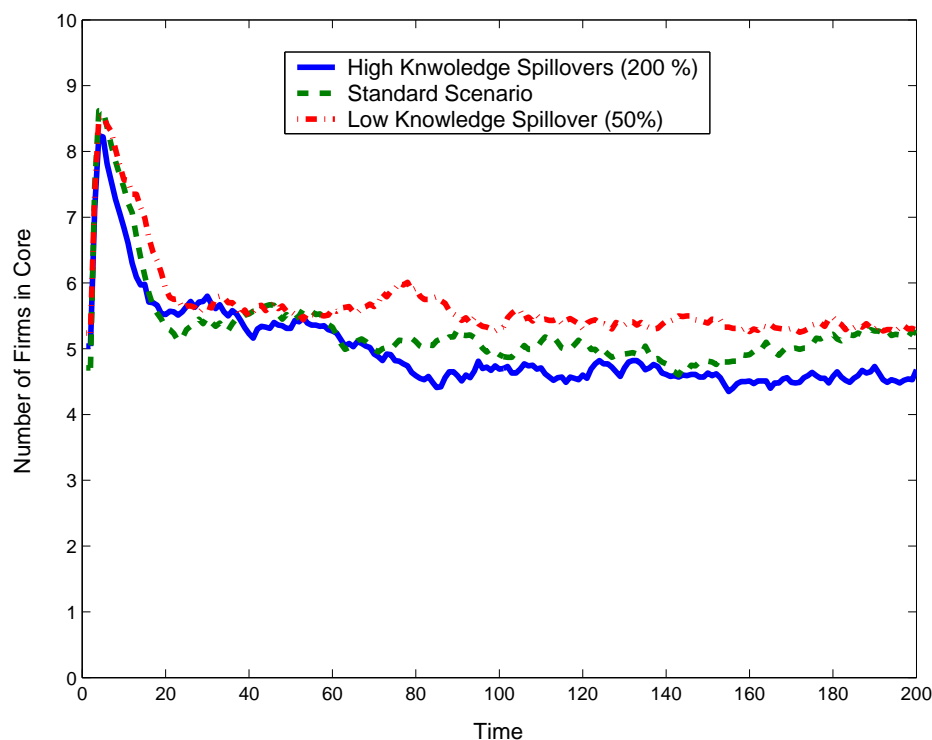


Figure 6.5: The impact of scale of knowledge spillovers on the number of firms at the core.

The curves stand for mean values of 100 simulation runs and have a similar pattern showing a high peak at the beginning of the simulation runs and a stabilization phase afterward. Over time differences between the scenarios become clear, where the graphs for low knowledge spillovers indicate most firms at the core and the graph for high knowledge spillovers the least number of firms settle in the agglomeration. The standard case is for most of the time sorted between the other scenarios. At period 200 statistical tests show a difference between the outcome of low and high knowledge spillover at a confidence level of 95% and between the standard and high spillover scenarios at 90%. The difference between standard and low spillover scenario at period 200 is not significant, see Appendix A.3.

The result of Figure 6.5 is rather interesting since it suggests a negative correlation of knowledge spillovers on the numbers of firms that wish to exchange knowledge in close geographical proximity. Higher local knowledge spillovers therefore even reduce the incentive for core holding all other factors constant. The more firms can learn from each other the less they are willing to participate in the learning process in order to secure their competitive advantages. In this model the quantification of positive and negative aspects of knowledge externalities predicts that the negative consequences will prevail.

Having discussed the evolution of the number of firms in the agglomeration we now turn to the question which type of firms seek geographical proximity. In order to analyze the profitability of firms Figure 6.6 shows the average aggregated profits over the firms which are located in each period either at the core or periphery. All values are calculated from the standard scenario and it is important to note that (as shown in graph 6.2) approximately half of the firms choose core and the other half periphery.

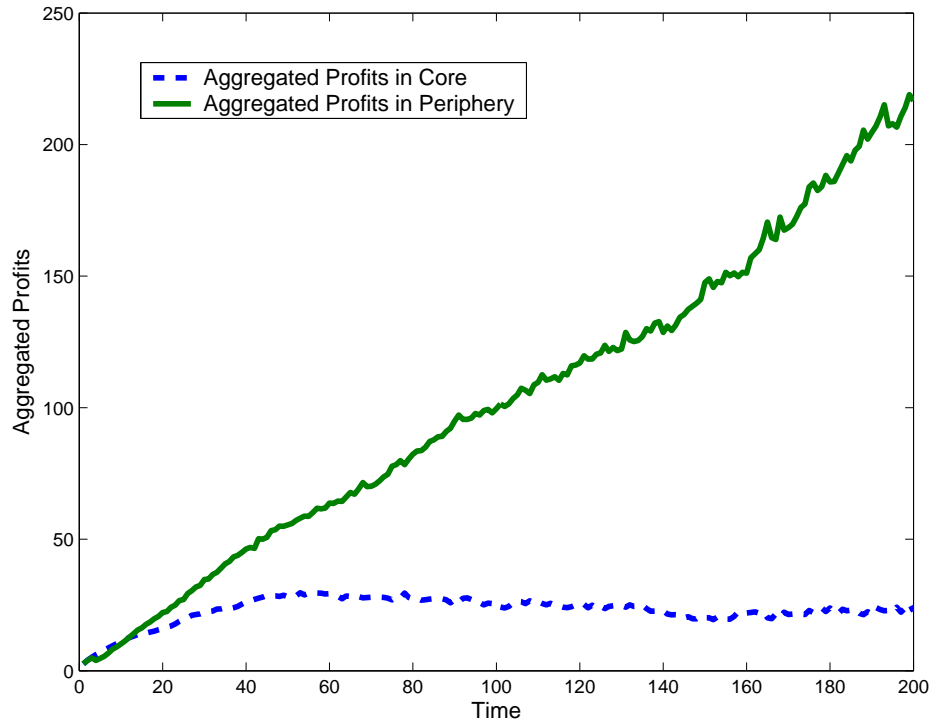


Figure 6.6: Average aggregated profits over all firms at the core and on the periphery in the standard case.

In contrast to the previous results of this section the outcome here is very clear. After an initial phase the average aggregated profits of the firms on the periphery exceed the average aggregated profits of the firms in the agglomeration although the number of firms in the two locations is almost equal. The average aggregated profits of periphery firms increase over the whole simulated time horizon whereas the average aggregated profits of core firms stay constant or even decline in the second half of the simulations. A statistical test supports the impression of the figure with a confidence level greater than 99%, see Appendix A.3. The outcome that periphery firms earn on the average higher profits, has proven to be very robust upon demand, firm strategy and parameter settings in the model. As we will see in Section 7.1, firms on the periphery are on the average not only more profitable but also more technologically advanced.

The answer to the question which firms seek the geographical proximity to competitors, is therefore: Mostly firms with low profits participate in the local learning process. On the average firms with high profits choose the periphery and succeed in raising their profits while the others want to learn but are only able to learn from other low profitable firms. The conclusion of Figure 6.6 can only be: There is a strong adverse selection effect in clusters.⁶ Only low profitable firms are attracted by the agglomeration in a horizontally differentiated industry given the assumption that all firms are competitors on the goods markets. In the setting of this chapter this kind of behavior could be explained in the way that technologically leading firms do not benefit from learning as they fear the loss of knowledge through involuntary knowledge spillovers and therefore choose isolation on the periphery.

In the literature Teece (1998) points out that most firms try to keep their knowledge assets secret in order not to share profits with other parties. According to Simmie (2005) this results in the fact that only firms with limited knowledge bases are likely to participate in local knowledge pools. The empirical investigation by Suarez-Villa and Walrod (1997) finds that clustered firms are less productive and less profitable. In the paper by Iammarino and McCann (2006) the authors presume that the argument of Akerlof (1970) can be applied to clusters, which results in a concentration of mediocrity. This argument may help to explain the empirical finding that many of the largest firms do not locate their R&D activities in close geographical proximity to their competitive rivals (Simmie, 1998; Cantwell and Santangelo, 1999; Alecke et al., 2006).

More precisely, an empirical work by Shaver and Flyer (2000) about geographical location decisions and survival of foreign greenfield investments in U.S. manufacturing industries discovers the adverse selection effect, that mostly technologically lagging firms choose to locate in an agglomeration. The authors find that if firms are heterogeneous, they will differ in the benefits in the cluster. They argue that technologically advanced firms will gain little or will even lose their competitive advantages through knowledge spillovers in an agglomeration. Therefore, these firms have low incentives to geographically cluster despite the existence of positive agglomeration externalities. Conversely, technologically lagging firms have little to lose and a lot to gain. Both situations result in an agglomeration of the technologically weakest firms with much lower profits. Our results of the model strongly support this analysis.

Other empirical studies in this context by Chung and Kalnins (2001) and Kalnins and Chung (2004) concentrate on the lodging industry in Texas. Here a positive externality comes in the form of demand gains of geographically closely located hotels. Again competition costs result from proximity since customers can very easy change their hotel. The authors discover agglomeration gains in rural areas but

⁶See Akerlof (1970) for the seminal model and description of adverse selection.

mostly only small hotels, which typically do not heighten demand, gain more. They also suggest that some establishments can be harmed, which leads to lower revenue performance than if there was no agglomeration. In Kalnins and Chung (2004) the location choice of entrants and possible spillover effect in the Texas lodging industry are analyzed. The authors find evidence that entrants will locate near others with resources that can spill over. But entrants will avoid agglomerations where competitors will exploit spillovers without contributing. Both arguments are in line with the findings of the model although the mechanism of spillovers is rather different.

Recent empirical research in the form of working papers continues the discussion of the location decision and the type of firms. In Aharonson et al. (2004) data of the Canadian Biotechnology Industry between 1992 and 2000 is examined. The findings suggest that entrepreneurial start-ups locate close to firms in the same technological specialization in order to benefit from knowledge spillovers. This occurs even if the incumbent firms may be better positioned to exploit knowledge gained from the entrepreneurs through spillovers. Pe'er and Vertinsky (2005) use data for *de novo* entrants into the Canadian manufacturing sectors during 1984-1998. Findings reveal a non-linear relationship between resources and capabilities and the value of localization economies for entrants, where weak firms with few resources may not be able to benefit from local networks or collaborations. In contrast to Shaver and Flyer (2000) the authors identify a favorable selection process in the lower range of resources and capabilities, where stronger entrants are more attracted to locations with agglomeration economies. But the adverse selection effect is given at higher levels of initial resources and capabilities of the firms. Thus, the stronger the entrants, the more they are detracted by local competition and incumbents' deterrence strategies. Another result of this work indicates that, although entrepreneurs are likely to stay in their area of origin, economic and strategic variables do matter for the location decision. A recent empirical study by Jirjahn and Kraft (2006) observes that knowledge spillovers from rivals are more valuable to laggard establishments.

Additionally to the adverse selection there emerges a lock-in effect which binds firms to the core once they choose agglomeration. But this is the topic of the following section about technological location.

6.3 Specialization and Coordination

The interpretation of technological proximity is connected to aspects of specialization as discussed in the previous sections. This section will add further details to the discussion about specialization and the interplay with geographical proximity. We start by introducing the development of specialization of the firms at the core and

on the periphery over time in the standard scenario in Figure 6.7.

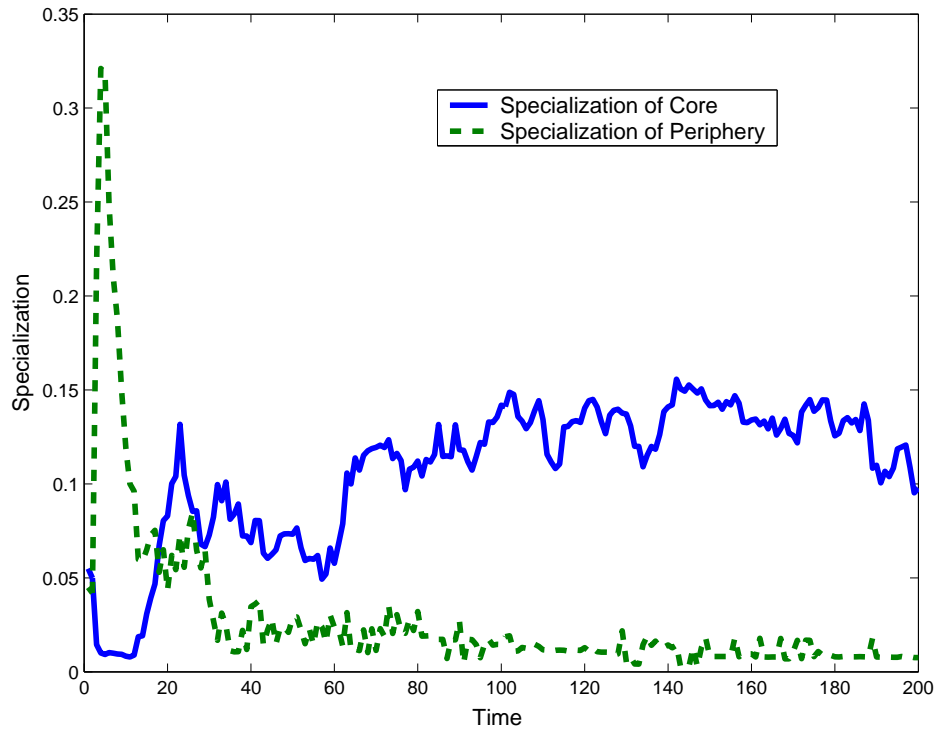


Figure 6.7: Specialization of core and periphery in the standard scenario over time.

Starting from a similar level for specialization many firms choose a location at the core because of the mentioned reasons, see Figure 6.2. As the single firms are by initial conditions highly specialized, more firms at the core lead to a diversified agglomeration and specialized periphery. This changes first slightly and afterward abruptly with the advent of the first product innovations shortly before period 20. The level of specialization of the different geographical locations changes afterward. Over time the agglomeration becomes more specialized and the periphery converges to a very low level of specialization.

In order to illustrate the aspects of technological proximity Figure 6.8 presents an example of the technology space of firms located either at the core or on the periphery. Each peak stands for the maximum value for the knowledge stock for process innovations chosen from all firms in that particular location. Although several firms are located in the agglomeration, they do not have knowledge in all types of technologies which exist at that point of time. Apart from the initial markets with the numbers 1 to 5, firms at the core do not have knowledge in the newly established markets 6-10. The high discrepancy in the height of the peaks and the difference in the location of the technologies with knowledge greater than zero make the agglomeration more specialized. Altogether the maximum height of the peaks appears to be lower than in the right picture, which indicates that

the firm's best-practice of core is again lower than the best-practice outside the agglomeration. This is true even in the major technologies of cluster firms. The fact that cluster firms do not have knowledge in any of the new markets indicates that the successfully innovating firms did not settle in the agglomeration. Otherwise some of the cluster firms would have obtained at least a low level of knowledge in the new technologies through external knowledge spillover. The innovators protect their valuable knowledge through the choice of secrecy in the isolation.

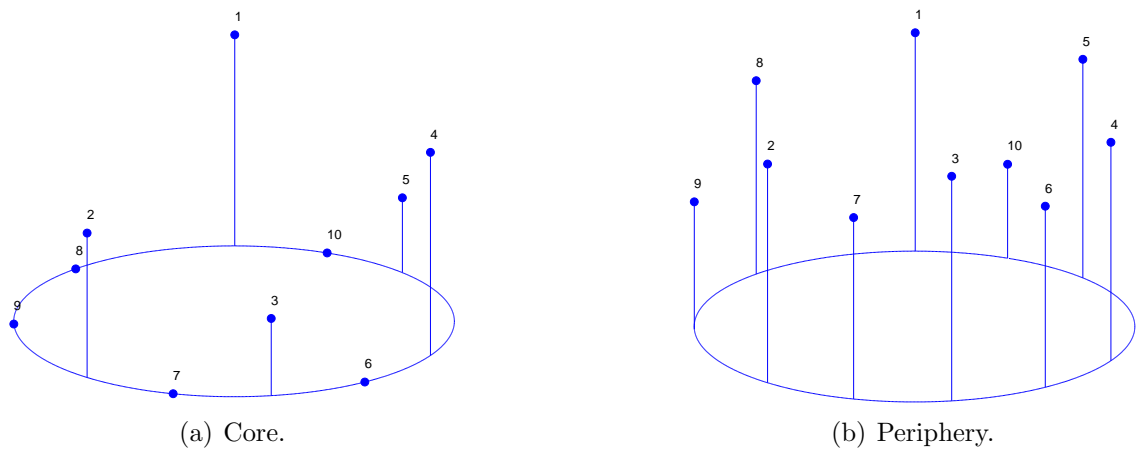


Figure 6.8: An example of the technology space at the core and on the periphery at period $t = 48$.

The situation on the periphery is rather different. Here in every technology at least one firm has a high amount of knowledge, which leads to positive peaks for every number in the picture. Interestingly, in this particular situation the knowledge in the more recent product variants (denoted by the numbers 6 to 10) almost reaches the level of the initial product variants 1 to 5. The height of maximum knowledge is different in certain technological areas but the differences are smaller compared to the situation in the technology space of the agglomeration. Additionally, the differences in technological distances between technologies are more similar. Both properties make the technology space of the firms on the periphery less specialized. As shown in the graphs of Figure 6.7 these differences on the average persist over time and do not converge.

One obvious explanation for the patterns shown in Figures 6.7 and 6.8 can be seen in the adverse selection of the agglomeration. Since mostly low profitable firms settle at the core, as seen in the previous section, the technology space consists of few isolated peaks. The more successful firms on the periphery invest more in R&D and are able to extend their knowledge by internal learning. Therefore, all firms on the periphery show a very balanced technological portfolio, which results in diversification.

The remainder of the section borrows from Dawid and Wersching (2006). In this paper we used a similar model to debate the influence of specialization on firm profits. Some of the results differ because a different formalization of the demand side was used. In Dawid and Wersching (2006) the total demand for a sub-market is calculated with half of the technological distance to the neighboring product variant. In contrast to the model of this book it is not possible for consumers to change the consumed product variant, see Section 4.2. The inflexibility of the consumers stressed the role of competition in certain technological areas, and therefore specialization has a greater impact on firms' profits. Hence, some of the results are different, which is always mentioned in the discussion. In general we admit that firm and consumer behavior in the latest version of the model, introduced in this book, are more plausible and in some sense more rational. This can for example be seen in the comparison with a random behavior of firms.

Coming back to the influence of specialization one can argue that although there is no complete consensus, there is some evidence that some technological specialization among firms of the same industry in a cluster has positive effects on spillovers, see Section 2.3. We adopt this view but also take into account that firms in a cluster are not only producers and receivers of knowledge flows but also competitors on the market. Strong technological specialization within a cluster leads to little differentiation between the products of the cluster firms and hence to increased competition among them. This is particularly true if we think of clusters which primarily serve local markets or industry-dominating clusters like Silicon Valley. Hence, the positive effect of intensive knowledge exchange in specialized clusters may be countered by negative competition effects. Competition considerations are also an important factor in determining which firms decide to enter a cluster in the first place as knowledge spillovers always flow in two directions. Thus a firm cannot prevent knowledge from spilling over to possible competitors in the cluster. A firm inhabiting a particularly profitable market niche or enjoying a technological lead might have strong incentives to choose geographical isolation on the periphery rather than joining a cluster.

The consideration of market competition might imply negative effects of specialization on profits which run counter to the potential positive effects on knowledge externalities typically stressed in the literature. In order to evaluate this trade-off in the framework of our dynamic industry model we present in Figure 6.9 the mean aggregated profits of all firms and the level of specialization of the industry after 200 periods in 100 simulation runs in the standard scenario.

As can be seen in the graph, there appears to be a negative relation between the aggregated profits and the specialization of the industry. This is confirmed by estimating a linear regression with average profits as dependent and specialization as explanatory variable, which gives a negative coefficient of the specialization index.

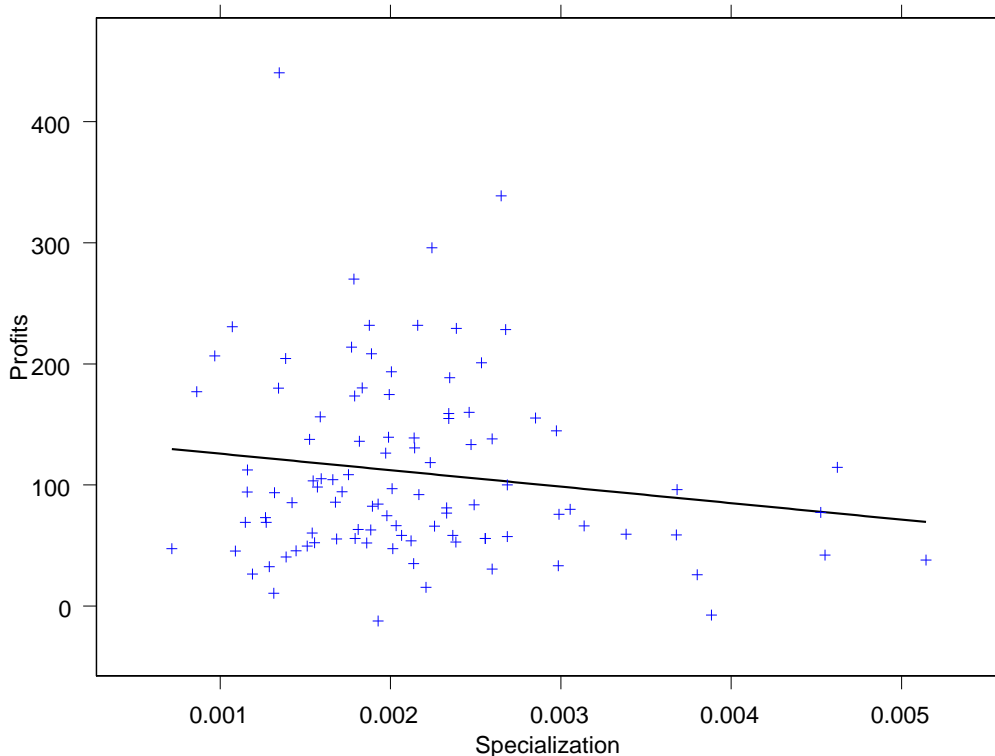


Figure 6.9: Average aggregated profits and specialization of the industry.

Obviously as shown in the picture the single variable does not explain much of the variance and the statistical results are rather bad ($R^2 = 0.02$, $t\text{-value} = -1.49$). In the similar model in Dawid and Wersching (2006) the statistical results show a higher correlation between the variables. One reason for this is the different formalization of the demand side, which in contrast to the model of this book does not allow the consumers to change the consumed product variant. Thus, in the earlier version of the model firms enjoying a high knowledge in isolated parts of the technology space are not threatened by product variants with low prices. This could be the reason why specialization has a greater impact on firms' profits and the results of the regression are more evident.

Several questions arise here. Is the negative correlation between profits and specialization a phenomenon associated with particular firm strategies concerning sub-market selection? Are there any normative implications for firm strategies? Is this effect more pronounced for firms who stay outside the cluster (as might be expected since these firms do not profit from the positive knowledge flow effects from specialization)?

To study the impact of firms' market selection strategies more closely we compare results from four different batches of simulation runs. In the first batch the decision of a firm where to position in the technology space in case of entry into an existing market or product innovation is random.⁷ We say that firms use a *random* strategy and use this batch as a reference case. In the other three cases potential locations in the technology space are selected according to the market evaluation function of the firm. The three batches differ with respect to the range of potential values of the two parameters determining a firms market-evaluation function: The weight put on current profits on sub-markets and the weight put on the distance of the market from the firm's current main technological expertise which is given by the technology where the firm has accumulated the largest stock of knowledge, see Section 4.3. If both strategy parameters are chosen from their full ranges, we refer to this case as the case with a *balanced* strategy. This is equal to the setting of the standard scenario. Furthermore, we consider two batches of runs where the value of a certain strategy parameter is restricted to a sub-interval of the full range. In one batch the parameter determining the weight of current profits is restricted to a sub-interval in the lower region of the full range. In this case we say that firms apply *knowledge-oriented* strategies. In another batch the weight of current technological expertise in the sub-market evaluation function is restricted to a sub-interval of low values. We say that firms use *profit-oriented* strategies. The changes of parameters in the different settings are given in Table A.3 in Appendix A.3. In what follows we compare these sets of 100 data points each with respect to crucial variables like profits and degree of specialization.

Figure 6.10 compares the industry dynamics under the four strategies with respect to the local dimensions of specialization of the industry, which is argued in Section 6.1 to be the more relevant dimension of specialization. Due to our initialization, each firm in the first period has a random knowledge stock in only one technology and the technological distances between product variants are also chosen randomly. Hence, initially the industry is already quite diversified and the level of specialization in location does not alter before the advent of the first successful product innovations. A statistical analysis of the situation at the end of the simulated periods is given in Appendix A.3.

The general patterns of the curves are similar in all scenarios but the resulting level of specialization differs. After the initial phase the first product innovations distort the technology space, which results in more clustered technologies indicated by a peak toward more specialization. Further product innovations lead in general

⁷To be more precise, the firm randomly picks a 'candidate' location in the technology space. However, before actually entering this market the firm checks whether the market evaluation exceeds a certain minimal threshold.

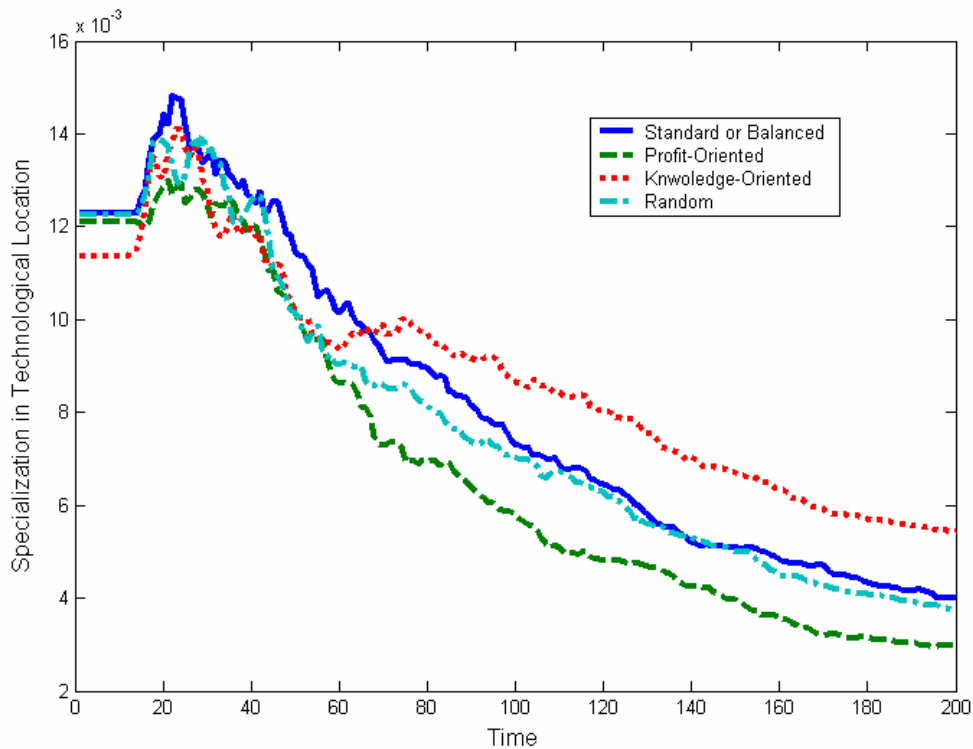


Figure 6.10: The impact of four firm strategies on industry specialization in location.

to a more uniformly distribution of technologies on the technological circle, which reduces the levels of specialization. The decline is rather different in the scenarios. The standard and random strategy graphs seem to converge over time, but most of the time the specialization in standard is higher. This is quite intuitive, because we should expect that with random strategies the sub-markets emerging over time will be distributed rather uniformly on the technology space.

If firms use a profit-oriented strategy the industry is even more diversified than in the random scenario. After the first new product variants are introduced in the market, firms in the profit-oriented scenario are eager to establish new products in relatively big market niches. Hence, their behavior leads to more uniformly distributed technologies in the technology space. After period $t = 60$ this generates less specialized industries in this scenario. It can be clearly seen that orientation of the firms toward short-run profits leads to almost parallel behavior of firms as far as market selection goes. One can show that this has a positive effect on the intensity of external knowledge spillovers between firms in the cluster. However, this is also limited by the downside of the strongly coordinated behavior induced by profit orientation, because firms at the same time build up knowledge stocks for different technologies at a similar pace, which implies that knowledge stocks are rather uniform in height and there is relatively little specialization of knowledge stock in

the cluster. But the sum of those effects still indicates that in the profit-oriented scenario the level of external knowledge spillovers exceeds the levels of the other scenarios considered.

As in all cases the more knowledge-oriented strategic behavior of firms leads to a first peak and a decline of specialization in location of the industry. Firms initially have heterogeneous technological expertise and a knowledge-oriented strategy keeps or even reinforces this heterogeneity. This implies that the scope for knowledge spillovers should be smaller if firms follow a knowledge-oriented strategy. This view is supported by an examination of the evolution of external knowledge spillovers. A major difference occurs around period $t = 50$ where the curve stabilizes and even increases for a while. This point in time could hint at a selection process between successful and technologically lagging firms similar to the arguments in Section 5.2.2. In this scenario the economically successful firms first search close to their major technological competencies, but as the industry evolves the most technologically advanced firms have several technological majors and start to serve even more distant technological areas. In consequence this results in declining overall industry specialization. But the highest levels of specialization of the industry are still reached in the scenario where firms base their market selection decision mainly on their existing technological strengths.

Looking at the specialization of firms in the different scenarios one can identify differences between specialization of location or height of knowledge stocks for process innovation. In the case of specialization of technological distances between sub-markets the profit-oriented scenario indicates the lowest, and the knowledge-oriented the highest values for specialization in location. The standard and random curves are located in between. The opposite is true in later periods for specialization in height, which is shown in Figure 6.11. Here, by assumption all firms start perfectly specialized and reduce their level of specialization due to investments in R&D or through knowledge spillovers. At the beginning firms that concentrate on their own technological focus are able to keep higher specialization values compared to the other scenarios. The situation changes completely during the next phase. In this time interval firms compete with each other and the consequences of the different firm strategies become obvious. As a result there emerges a pattern where profit-oriented strategies lead to highest and knowledge-oriented to lowest specialization in the height of knowledge for process innovations. Statistical tests of the outcome also support this result to a confidence interval of at least 90%, see Appendix A.3.

Summing up, one can say that a scenario where firms tend to follow short-run profits rather than expanding from their technological core competencies leads on the average to more diversification in technological location and more specialization in the amount of knowledge. This means that on the average firms in the profit-oriented

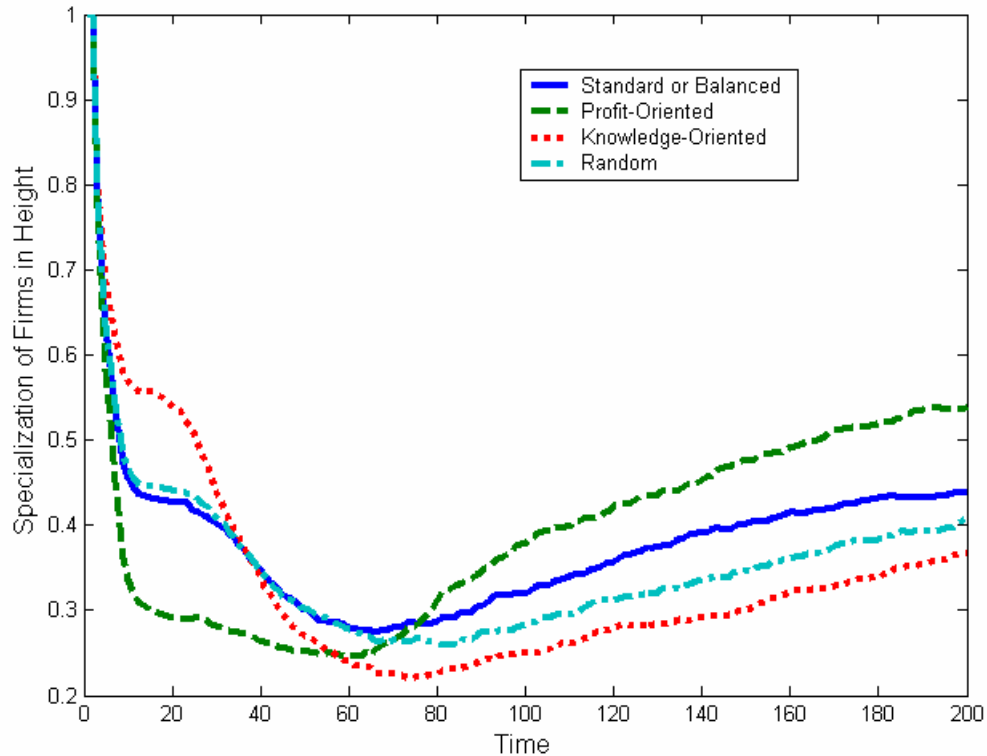


Figure 6.11: Average firm specialization in height of the knowledge for process innovations.

scenario have knowledge peaks of very different height, which are spread over the whole technology space. Firms do not have a clear core competence, instead they have more basic knowledge in most areas and some regions where they are close to the best-practice level of the industry. The overall level of knowledge spillover is high but learning is not very clearly guided toward a certain technological area. On the other hand, firms in the knowledge-oriented industry possess knowledge peaks of similar height but only in a particular technological area. This is of course driven by the assumed strategic behavior of entering close markets and introducing close product innovations. But knowledge spillovers also foster local learning. Knowledge build-up is highest at the frontier of the area of competence as a medium technological gap and a small technological distance to the main knowledge of the firm supports fast learning. Both constellations result in very similar knowledge height.

The discussion shows that the type of market selection strategies firms follow has substantial impact on the degree of specialization arising in the industry and the firm. The impact of the different strategies on average profits is depicted in Figure 6.12. The order of the curves at the end of the simulated periods is just the opposite of the later periods of Figure 6.11, which is of course no coincidence. We tested the

outcome at the end of the simulated periods and the ranking was significant except that the values for random are not significantly higher than standard but higher than profit-oriented. For more details please refer to Appendix A.3.

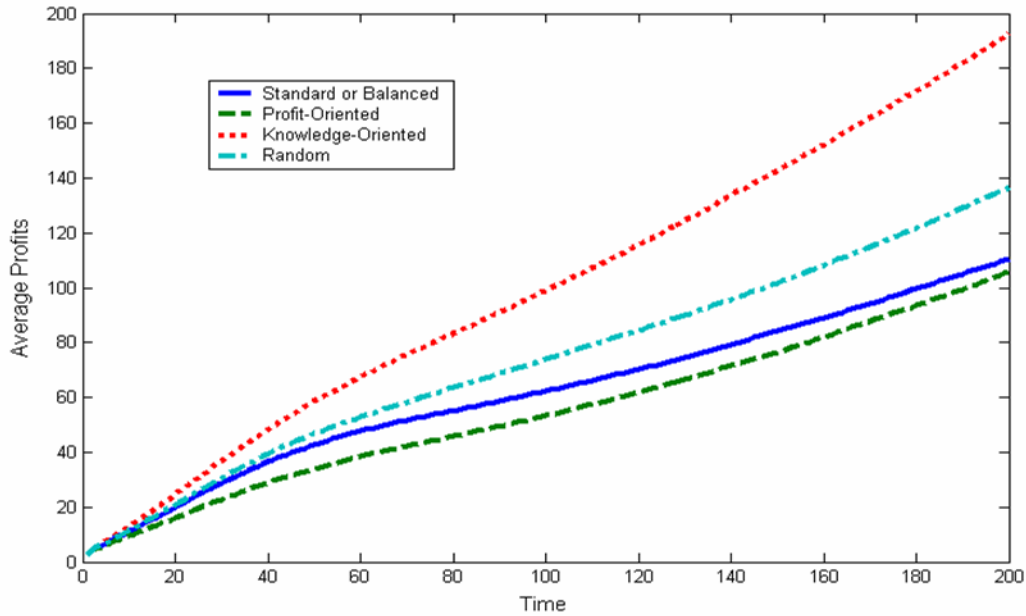


Figure 6.12: Aggregated profits for different firm strategies.

Quite surprisingly, profits are on the average lowest if firms follow a profit-oriented strategy whereas largest profits are made in an industry where firms follow a knowledge-oriented strategy. In Dawid and Wersching (2006) most profits were earned in the random scenario followed by the knowledge-oriented scenario. This appears to be so because of the different demand setting. The profits under the random and balanced strategies lie between these two extremes, where profits under the balanced strategy are rather close to those under the profit-oriented strategy. Considering the effect of competition on the market is crucial to understand this ranking. The attractiveness augmented structure of demand implies that products far removed in the technology space from the other active sub-markets attract higher demand at equal price and therefore tend to yield higher profits. Accordingly, any strategy leading firms to position their products close to the competitors has detrimental effects on revenues. For firms that are in the cluster such a strategy on the other hand facilitates cost-reducing technological spillovers. However, our results indicate that the negative revenue effect outweighs the positive cost effect. These considerations imply that for all strategies which are not random the fact that all firms use the same evaluation strategy by itself has negative effects on the average industry performance. We have verified this observation by running simulations

where a single firm using the profit-oriented / knowledge-oriented / balanced strategy is inserted into an industry where all other firms employ the random strategy. For all three types of strategies we found that the non-random strategy performed statistically significantly better than the random strategy.

Beside the firm strategy itself, another reason for the occurrence of such excessive coordination are the spillover effects. If a cluster firm accumulates a particularly high knowledge stock for a certain technology, spillover effects imply that all other cluster firms also attain a high knowledge stock in that technology region. Hence, the technological focus of many other cluster firms might move into the same technological region and accordingly these firms will concentrate future production and product innovation in that region. Put differently, the existence of technological spillovers makes it hard for firms to keep their distinctive technological profile if they settle in the cluster. So, even under strategies like the knowledge-oriented strategy, which *per se* does not promote technological uniformity, there is a strong tendency toward specialization in the cluster.

Finally, it should be noted that in spite of the large differences in profits between periphery and cluster firms there is no strong flow of firms from the cluster to the periphery. Cluster firms could not profit from moving out of the cluster because such a move would not alter the profile of their knowledge stock and accordingly they would still have to produce for sub-markets which are close to the technological focus of the cluster. Even worse, they would lose the technological spillover effects and might eventually be less cost-efficient than the remaining cluster firms. Hence, there is a technological lock-in effect which ties the firms to the cluster even though periphery firms are more profitable. This argumentation is in line with the result of the previous Section 6.2 that not many firms leave the cluster and the argument that core is more specialized than periphery proposed at the beginning of this section in connection to Figure 6.7.

In the management literature the topic of coordination is discussed in the field of dynamic capabilities, see Section 2.1. Typically, in this approach the firm is advised to develop a core competence in a certain technological area when aiming at long-term performance (Wang and Ahmed, 2007). This finding is in line with the result of this section that a knowledge-oriented strategy helps to constitute knowledge assets, which results in greater profits. But it is important to note that the precondition for this result is the heterogeneous distribution of knowledge at start. On the other hand, a more homogeneous distribution of knowledge does not lead to the same average profit level because of the more coordinated market behavior.

In a similar simulation approach Dawid and Reimann (2005) provide an extensive analysis of profit versus market growth oriented firm behavior, where they examine the influence of different market evaluation strategies on overall outcome

in a dynamic industry. In their setup average profits are higher if all firms follow a profit-oriented strategy, but later firms are allowed to change their evaluation strategy according to a simple adaptation dynamic. With strategy adaptation firms tend to follow a market growth oriented strategy, which results in lower average industry profits. Further, it is shown that the degree of horizontal product differentiation is significant for the incentive to change firm strategy.

The potential disadvantages of coordinated firm behavior are stressed by the theory of strategic balance (Deephouse, 1999), too. Here the author proposes that firms have to balance between a differentiation and conformity proposition. The first differentiation proposition holds that firms should have different strategies than their competitors in order to avoid competition, and the second conformity proposition points toward potential negative effects on firm profitability through legitimacy challenges. As a conclusion of his theory, Deephouse (1999) argues that moderately differentiated firms have highest performance, which is also supported by an empirical investigation in the same article. In Oerlemans and Meeus (2005) this theory is tested in the context of innovation strategies with data from the Netherlands. The paper gives empirical evidence that the more firms deviate from a sectoral mean with their innovation strategies, the lower is their average annual growth of employment or sales. This outcome confirms the strategic balance theory. However, in the case of relative innovation outcomes a higher level of dissimilarity seems to be beneficial. In short, Oerlemans and Meeus (2005) conclude that being different pays out when it comes to innovation, which is again the same argument as in our model.

Furthermore, the topic of coordination is also connected to the question what kind of environment favors knowledge spillovers - either specialized (MAR spillovers) or more diversified (Jacobs spillovers), see Section 2.3. So far the literature on technological spillovers and specialization has focused on the question how the intensity of spillovers is influenced by the degree of specialization. Our findings suggest that there might be an opposite effect such that spillovers yield technological specialization and that under consideration of market competition such an effect provides negative incentives for joining a cluster. Therefore, not the technological surrounding determines the degree of knowledge spillovers but rather knowledge externalities shape the environment.

6.4 Summary

This chapter is devoted to the analysis of firm strategies in the virtual industry described by the theoretical model. Main focus is set on the investigation of firm behavior which is captured in parameters for firm strategy. The chapter links the assumed environment and firm conditions to the outcome on geographical and tech-

nological proximity from the perspective of a firm.

We start Section 6.1 with our interpretation of specialization. The technological profile of a single firm or a group of firms can be described with a specialization index. This index considers two types of specialization, namely specialization in location and height of the knowledge peaks in the technology space. Afterward the influence of firm strategy parameters on firm profits is examined with the help of a regression analysis. The outcome suggests that in the standard scenario firms which quickly enter new markets, stay longer in active markets, or put more weight on attractive market niches earn greater profits. Strategy parameters for geographical location are not significant in the regression.

The following Section 6.2 concentrates on aspects of geographical proximity. It is argued that there is a high incentive for a location in the agglomeration but this incentive declines as the industry becomes more mature. Higher external knowledge spillovers even enhance this effect so that higher learning possibilities even drive firms out of the cluster. As the industry ages, internal learning becomes more important than external learning through knowledge spillovers. The perhaps clearest and most robust result in this book is the finding that the aggregated profits of cluster firms are much lower than the profits of firms in isolation. This rather surprising outcome of adverse selection emerges not despite but because of local externalities. As discussed in this context we find empirical evidence for such a behavior in practice.

The results of firm strategy concerning technological proximity are the topic of Section 6.3. Simulation runs of the standard scenario show that the agglomeration is much more specialized than the periphery. An example of the technology space is introduced in order to illustrate the aspects of specialization. Next, the possibility of a negative relation between a specialized industry and average firm profits is debated. Firm strategies determine specialization of the whole industry as well as specialization of firms. A scenario where all firms follow a profit-oriented (knowledge-oriented) strategy leads to firms that are characterized by a high (low) specialization in height and low (high) specialization in technological location. Apart from the assumed behavior the internal and external knowledge spillovers drive this emergence. The average profits are highest in a knowledge-oriented and lowest in a profit-oriented industry. The parallel behavior and the coordinating role of knowledge spillover might be the cause for this outcome. The coordination mechanism also ties firms to the agglomeration, which constitutes a lock-in effect.

At the end of this chapter we come back to the question about the best strategy for a firm. In this particular setting firms perform best if they focus on their own strengths and mainly expand their knowledge around their technological core competencies. Firms should also avoid close geographical proximity to their direct competitors because the possibilities for external learning do not outweigh the loss

of competitive advantages. Both pieces of advice tend to avoid excess coordination which could emerge either through a coordinated strategy itself or through local learning. The knowledge spillovers in an agglomeration are limited due to the adverse selection effect for a technologically advanced firm especially. As the competitors become more equal in their knowledge assets, competition is enhanced, which results in lower profits.

There are of course also exceptions to the general rule, e.g. in an industry where all firms have similar strategies or knowledge in a particular field a firm could be better off by concentrating on previously not served market segments. Maybe this explains the different results in Section 6.1, where firms focusing more on market potential than on their own knowledge competencies prove to be more profitable in the standard environment. Here firm strategies are similar, such that on the average profitable markets and technological focus have the same weight. In that surrounding a firm could gain from profit-oriented behavior as shown in the regression of the parameters. For example if all automobile companies are eager to serve mostly high-cost luxury markets, an automobile producer could gain from concentrating on low-cost segments. Similar arguments can be formulated for policy advice if governments in all industrialized countries support a certain type of technological agglomeration, e.g. Biotechnology. This brings us to the topic of the next chapter.

Chapter 7

Public Policy

This chapter is devoted to the discussion of public policy. In doing so we take the perspective of a consumer or politician and ask how to foster the technological development of the industry, how to enforce competition, and how to increase welfare in the virtual industry. We start by taking a closer look at the impact of geographical proximity on the technological development of the industry. Further, we investigate the outcome of innovative competition in different technological environments. We then turn to the important discussion of different policies which could have a positive influence on the technological outcome and welfare of the industry. It will be interesting to see whether the positive influence of innovation policies, recommended by the literature, is evident in the setting of this model. The last section concludes the main points for public policy.

7.1 Agglomeration, Technological Development and Welfare

In the previous chapter we have shown that the outcome for average aggregated profits differs between core and periphery. The assumption of localized learning in geographical and technological proximity drives this result. We now turn to the analysis of the technological development which is understood as the progression of process and product innovations over time.

We start with an examination of knowledge for process innovations that determines the production cost of a product variant. In order to see the differences between the two possible geographical locations, Figure 7.1 presents the outcome for the maximum and average values of process innovations. All lines stand for 100 repetitions of the standard scenario.

The highest values of a firm in any technology is indicated by the best-practice level and the average knowledge of process innovation stands for the height of pro-

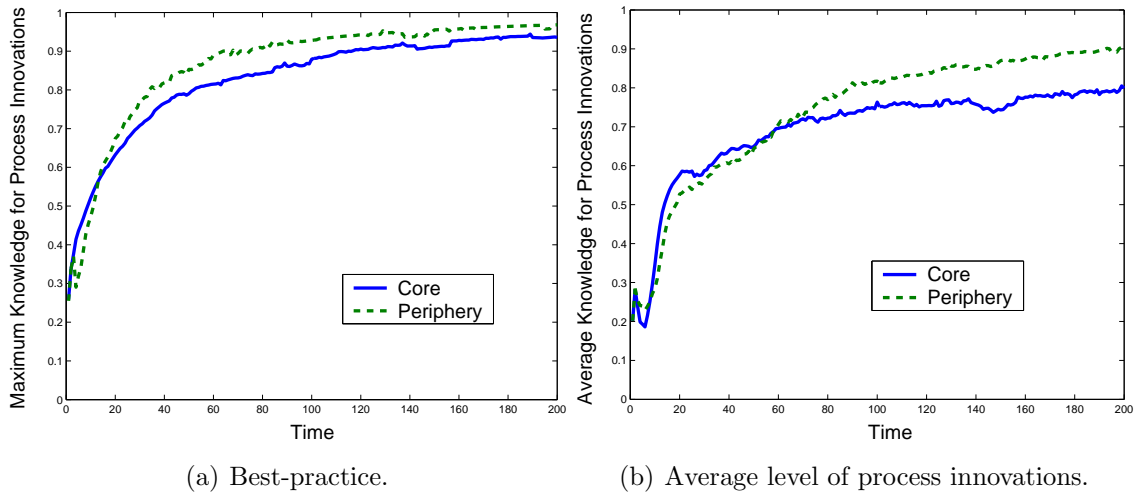


Figure 7.1: The maximum and average knowledge for process innovations over time.

duction cost over all current technologies. The first aspect describes the technological frontier, while the second index gives an idea of the distribution of knowledge over all agents. In Figure 7.1 a) the evolution of the maximum value for the knowledge for process innovations is depicted. The starting level is given due to the highest draw of a firm from a normal distribution with mean $RD^0 = 0.2$. During the first periods several firms change their location from periphery to core, which leads to higher values for core.¹ After that the graph for periphery lies above the curve for core as firms leave the cluster in order to protect their knowledge in the newly established technologies. Both curves converge to the assumed maximum of 1 and they follow the functional form based on the assumption that it is more difficult to gain additional knowledge the higher the achieved stock of knowledge. At the end of the simulated periods the best-practice level of firms on the periphery is still higher than that of firms at the core. This is also true for the average level of process innovations presented in Figure 7.1 b). Both results are supported by a statistical test with a confidence interval greater than 99%, see Appendix A.3.

Figure 7.1 b) demonstrates the mean of knowledge in process innovations starting on the average at $RD^0 = 0.2$. As the average is calculated over technologies with positive knowledge, gaining knowledge in technologies new to the firm might lead to falling average values. Exactly this happens at the beginning of the simulation runs, where firms expand their knowledge base in new areas with their own investments in R&D and through external and internal learning. After this initial phase the mean for process innovations increases more in core than in periphery. In comparison to a) the average values for periphery exceed those for core at a later period around

¹For the development of the number of firms at the core see Section 6.2 and in particular Figure 6.2.

$t = 60$. Although the number of firms at the core is significantly reduced after period $t = 20$ firms need a longer time to substitute learning from competitors at the core through internal learning and their own R&D. After that the difference in the mean level persists and even increases over time. An extension of the simulated time horizon to 500 periods shows that the difference in average knowledge persists but the difference in the maximum value for knowledge disappears. Hence, in the long run firms at the core might have a similar highest knowledge for process innovations in at least one technology, but firms on the periphery have higher mean knowledge.

After the discussion of process innovations, we introduce the outcome for successful product innovations in Figure 7.2. We use two boxplots² to analyze the outcome of 100 simulated iterations and to differentiate whether a product innovation was successfully conducted at the core or on the periphery. The picture indicates that more product innovations are introduced by firms that at that moment are on the periphery than at the core. Again the statistical tests support this impression, see Appendix A.3.

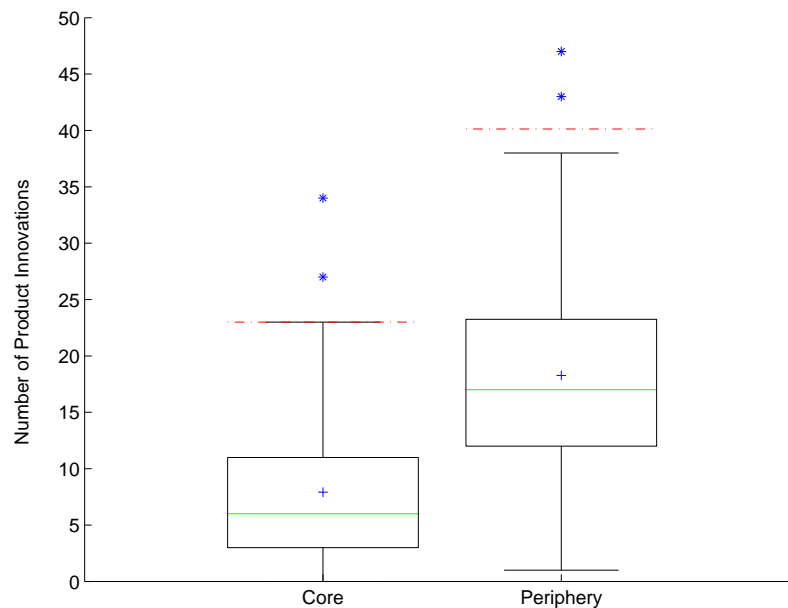


Figure 7.2: The number of successful product innovations and their geographical origin in the standard scenario.

From the comparison of core and periphery we conclude that after an initial phase firms on the periphery display a higher best-practice level, in average more knowledge for process innovations and introduce more new product variants to the industry. The difference is greatest when looking at the number of newly established products. This has a major influence on the benefits of peripheral firms due to mar-

²The boxplot function used for presentation in MATLAB was programmed by Ernest E. Rothman.

ket competition. These findings are in line with the results of the previous chapter, where it was shown that firms on the periphery earn in average greater profits. Hence, the better technological development of firms in geographical isolation leads to a better standing in the markets, which generates profits.

So far we have discussed the impact of agglomeration on the technological development in the standard scenario, where firms are free to change their geographical location. In the following investigation we compare the technological development of an industry if we keep the location of firms fixed.³

Thus the following analysis is based on four scenarios which differ on the number of firms at the core:

- **0% core:** All firms are always on the periphery. No learning can happen between firms but firms can make use of internal knowledge spillover.
- **50% core:** Half of the firms are located on the periphery, the other half at the core. Firms are not allowed to change their geographical location.
- **Variable:** This scenario represents the standard scenario with the decision rule for changing the geographical location as described in Section 4.3.3. Firms start with a random location and are free to move as they can afford it.⁴
- **100% core:** All firms are always at the core. Firms profit from externalities arising from knowledge spillover, but they might also lose their technological lead pretty fast.

In the considered settings we continue with the discussion of product innovations. The main difference between the two types of product innovations is that only radical product innovations expand the technology space whereas incremental product innovations just reduce the technological distance between two existing product variants. To generate a radical product innovation the knowledge for product innovations of a firm has to exceed a certain threshold. Knowledge beyond that threshold increases the probability for a radical product innovation.⁵ In order to get a closer look at the different types of product innovations Figure 7.3 presents boxplots of the total number of radical product innovations in a) and incremental product innovations in b) for all simulated scenarios.

The first observation of Figure 7.3 is the fact that in all scenarios firms conduct more incremental product innovations than radical product innovations. This is

³The remaining part of this section is built upon Wersching (2007a), where these topics were mentioned for the first time using an earlier version of the model.

⁴On the average about 50-60% of firms were located at the core. Therefore this scenario is placed between 50% and 100% core.

⁵For more details see Section 4.1

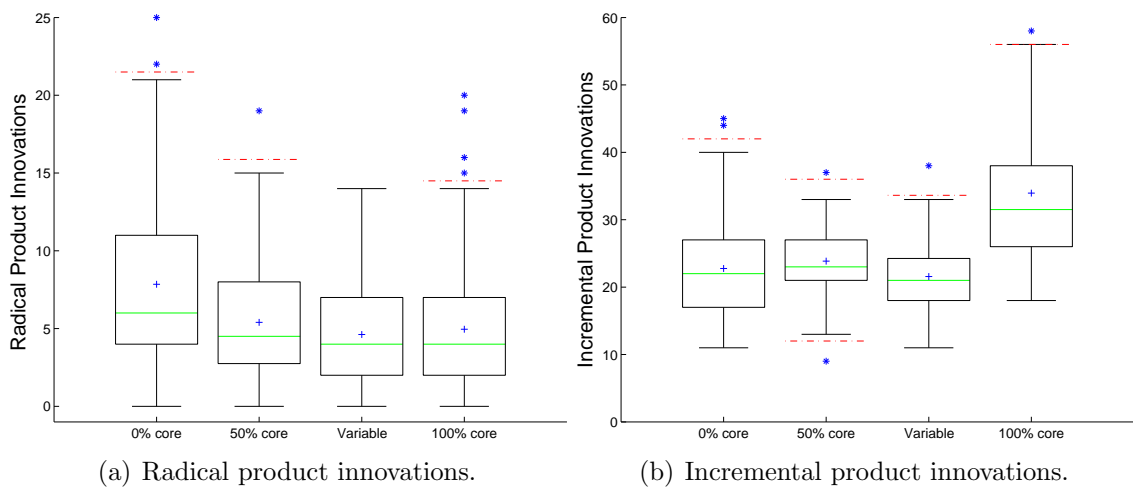


Figure 7.3: The number of firms at the core and the outcome for radical and incremental product innovations.

of course driven by the assumption that less knowledge is needed for incremental product innovations. The distribution of product innovations over the scenarios does not give a unified picture whether more or fewer firms in the agglomerations lead to more product innovations. Indeed the situation is rather different for the two types of new product variants.

In the case of radical product innovations there seems to be a negative relation between the number of successful radical product innovations and more firms located in the agglomeration. Most radical new products are given in the 0% core scenario followed by 50% core and fewest radical product innovations are observed in variable or 100% core. Statistical tests support this ranking and show that there is no significant difference between variable and 100% core, see Appendix A.3. Looking at the settings with fixed location this means that the lower the number of competitors learning from each other in close geographical proximity the more likely are radical product innovations. In the extreme case of 0% core all firms are geographically isolated and can only increase their knowledge through R&D projects of their own and through internal learning. Thus, imitation is difficult (in 0% core impossible) for competitors and firms concentrate their innovation efforts on areas in the technology space where they already possess knowledge. Since the firms' knowledge build-up is not connected via external learning, it is more likely for firms to have higher knowledge stocks in only a few but not very common technologies. As not many competitors have the necessary high amount of knowledge in a technology, an early (incremental) product innovation becomes less probable. Additionally, this argumentation is supported by the outcome that the fewer firms are at the core during the simulated periods, the higher is the average firms' specialization

in height. Therefore, no possibilities to enjoy external knowledge spillovers in this model increase the number of radical breakthroughs.

The situation for incremental product innovations is depicted in Figure 7.3 b). In the settings where firms are not allowed to change their location there is a significant relation between the number of firms at the core and the number of incremental product innovations. Apart from this outcome statistical tests in Appendix A.3 show that the setting with free choice of location generates fewer incremental product innovations than 100% core and 50% core, but there is no significant difference to 0% core. The bad performance of the variable scenario is quite surprising. Probably the adverse selection effect discussed in Section 6.3 is the reason because only technologically advanced firms leave the agglomeration and hence do not profit from external learning. In the scenarios with fixed locations it is not possible for a cluster firm to protect its knowledge assets, which increases the amount of knowledge spillovers. There is evidence for this because after an initializing phase the sum of external knowledge spillovers for product innovations is greater in 100% core and in 50% core than in variable. This greater amount of external learning results in more incremental product innovations. Hence, more external knowledge spillovers in the agglomeration generate higher average knowledge for product innovations. Since several firms might have high knowledge in the same technologies, the probability is high that one of those firms introduces an early incremental product innovation. This might alter the evaluation of the others such that they change their current interest in innovations and, thus, do not reach the threshold for radical product innovations. Further, the external learning changes knowledge stocks more gradually, which also works against radical product innovations. On the other hand, the firms' own investments in R&D lead to more abrupt increases in the knowledge for product innovations. Hence, the probability to reach the threshold needed for radical product innovations is higher.

We conclude that the existence of knowledge flows at the core has positive effects on the number of incremental product innovations developed in the industry compared to a scenario where fewer firms are at the core. The situation is the opposite for radical product innovations. Here, the scenario with no external knowledge spillovers indicates the highest number of radical product innovations. There is some empirical evidence for this outcome in a recent study by Jirjahn and Kraft (2006). The authors in their German firm level data find that knowledge spillovers from rivals have a positive impact on incremental innovations but no influence on radical innovation activities.

We continue with the discussion of process innovations to see whether we can find a similar result with the maximum and the average level of knowledge - but now knowledge for process innovations.

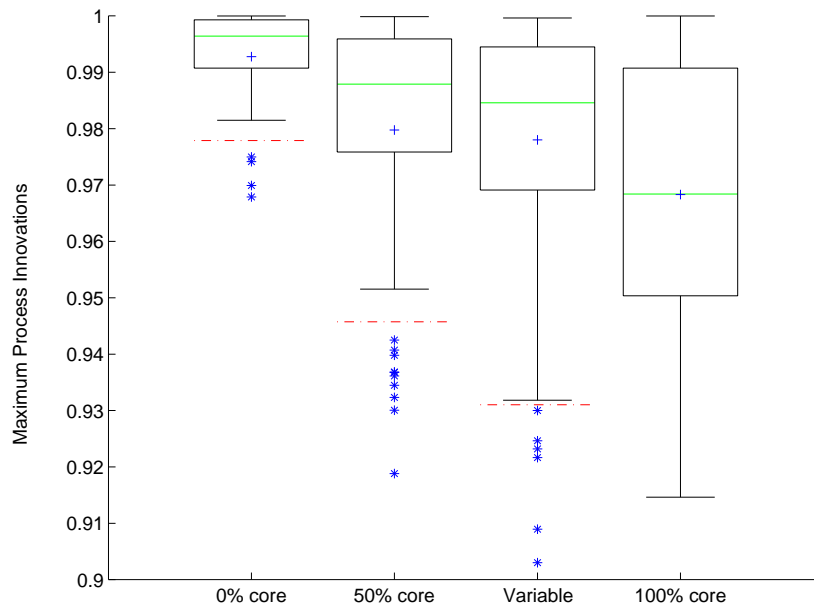


Figure 7.4: The number of firms at the core and maximum process innovations.

The level of the knowledge stock for process innovation reached at the end of the simulations for all settings is presented in Figure 7.4. The level of knowledge for process innovation has a direct influence on the production costs of the corresponding product variant. Obviously, the assumed upper border of 1 for the knowledge stock distorts the distribution of the results. Further, one can see that with an increasing number of firms at the core the mean and median decrease and the variance increases. Therefore, a small number of firms (in the extreme case no firms) that exchange knowledge through external learning seem to favor the maximum value for process innovations. This outcome is similar to that of radical product innovations and the argumentation is the same: As firms concentrate on fewer technologies and knowledge is mostly increased through investments in R&D and internal learning the best-practice level of the industry increases. The evidence of this negative relation between firms at the core and best-practice is underlined by the statistical tests in Appendix A.3.⁶

The evolution of the average level of process innovations over the whole time horizon in all four scenarios is shown in Figure 7.5. As already mentioned at the beginning of this section, the average values first decline because firms extend their knowledge assets to previously unfamiliar areas. In the first periods the evolution is similar in all scenarios and emerges because of the assumed initial conditions. But after period 20 the increase of the average knowledge is rather different.

⁶In Wersching (2007a) there is no significant difference between the maximum values in the several fixed locations but variable has the highest level of process innovations. Here the result in the setting with free choice of location is quite plausible for the overall picture.

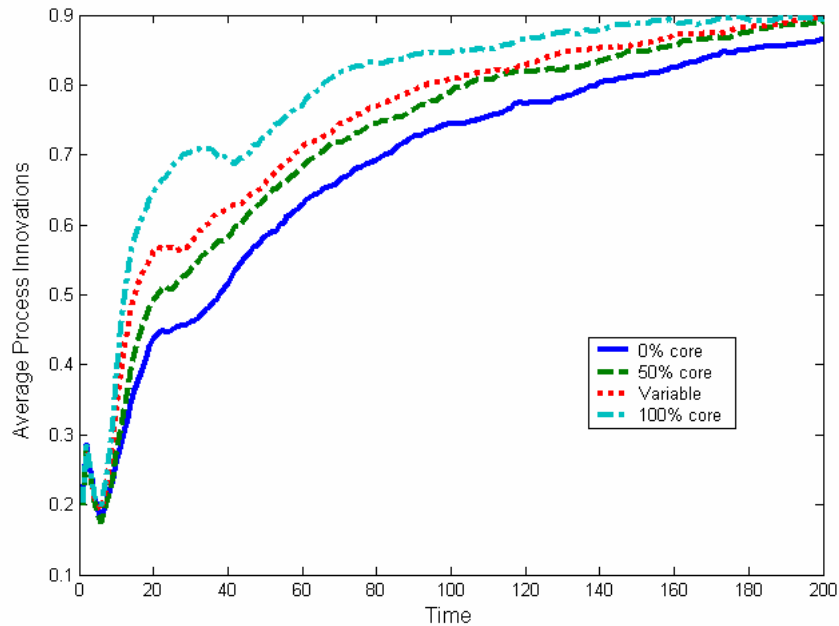


Figure 7.5: The number of firms at the core and the average process innovation over time.

Figure 7.5 gives an idea of the diffusion of knowledge for process innovations over time. The considered scenarios differ in their share of firms that take part in the local learning process in the agglomeration. Despite the fact that in every case there is an increase of the average knowledge, external knowledge spillovers seem to have a clear influence on the rate of diffusion. The curve for 100% core shows the highest values over time followed by variable, 50% core and 0% core. Even the graph for variable lies very close to 50% core, which is in line with the observed average share of cluster firms about 50-60% in variable. The sorting of the graphs is stable after period 20, but in the long run the graphs converge to values close to 0.9 and the difference between the graphs decreases. According to tests in Appendix A.3 at time $T = 200$ there is no significant difference left, but for example at $T = 100$ the ranking of the figure appears to be significant to a confidence level greater than 95%.

The outcome for process innovation is the same as for product innovations: More possibilities for external learning through knowledge spillovers in the agglomeration lead to a higher mean of knowledge or more incremental product innovations but in the same way to lower best-practice level or less radical new product variants. It appears that there is a trade-off between an industry where the firms have more general knowledge and knowledge spillovers lead to a fast diffusion between agents and a situation without knowledge externalities which induces higher levels of best-practice. So far it is not obvious which situation should be favorable from a political

point of view. If politicians put more weight on the quantity than on quality aspects, an industry with local learning should be preferred because in that case in total more product innovations occur and the sum of knowledge flows rises sharply.

The question whether firms in agglomerations are more innovative is the topic of an empirical study by Beaudry and Breschi (2003) which is related to Baptista and Swann (1998). Whereas Baptista and Swann (1998) find a positive effect of the clustering of firms of the same industry on the probability of a firm to innovate, the result by Beaudry and Breschi (2003) is not that obvious. Here the authors could identify positive and negative effects, which depend on the type of firms and employees located in a region. Further analysis shows that an agglomeration of innovative firms in a firm's own industry has a positive and statistically significant influence while a strong presence of non-innovative firms has a negative and statistically significant effect on the firm's innovative performance. Thus, the simulated outcome that more innovations occur the more innovative firms are located in the agglomeration can be underlined by empirical evidence. Apparently, further research has to put more emphasis on the analysis of the firm properties and a differentiation between incremental and radical innovations in order to test the other findings of the model.

After the debate about the innovative outcome we continue with the achieved average level of accumulated profits in all scenarios. The average aggregated profits in all scenarios are shown in Figure 7.6 and additionally the variable scenario is split into the average of all firms at the core (variable-core) and all firms on the periphery (variable-periphery) at $T = 200$. From the figure and the statistical tests in Appendix A.3 the following observations can be made: First, the higher the number of firms in the agglomeration in the settings with fixed location, the lower are the resulting average aggregated profits. This fact is given due to the lower values in the boxplots which are significant to a confidence interval greater than 99%.⁷ Second, the average aggregated profits in the variable scenario over all firms can be sorted between 0% core and 100% core. Third, looking at the data for variable in detail, we find that firms at the core have the lowest and firms on the periphery the highest level of aggregated profits. The first result is significant and the later outcome for periphery firms is not significant in the tests but the mean and the median for variable-periphery are higher than in 0% core. Probably, more simulated iterations would lead to a significant result of the statistical test.

The negative correlation between firms in the agglomeration and average aggregated profits can be explained with the local interaction at the core. As firms have more possibilities to exchange knowledge, they become more similar and competition on markets is enhanced as firms do not enjoy high knowledge leads. This is

⁷The previous analysis of average savings in Wersching (2007a) did not show any significant differences in the scenarios with fixed locations.

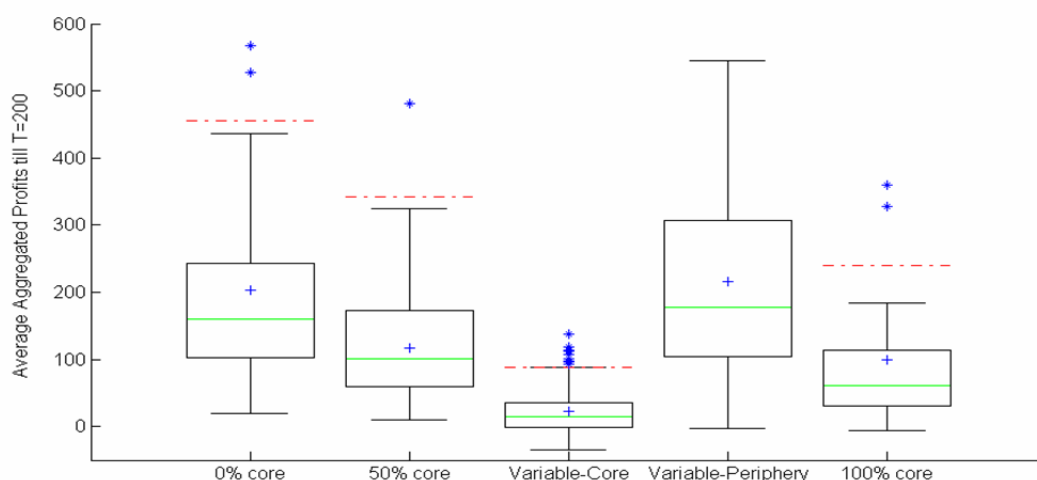


Figure 7.6: The number of firms at the core and the average aggregated profits.

also connected to the relatively high level of average process innovation in the scenarios with more firms at the core, see the previous Figure 7.5. Additionally, we discover decreasing prices with more firms settling in the agglomeration. Therefore a firm would on the average be better off choosing periphery rather than core, if all competitors are in the same location.

The outcome in variable can be connected to the adverse selection effect in clusters, which is the topic of Section 6.2. Although the average aggregated profits fit in the picture of the other boxplots, there is a relevant difference between cluster firms and firms on the periphery. If the choice of location is possible, firms that locate at the core are less profitable than in 100% core. The adverse selection mechanism in combination with the lock-in effect clearly produces this outcome. Though a firm would prefer a situation like 0% core to variable, the choice for core or periphery in variable is not clear since the clustering of less profitable firms at the core emerges endogenously. As Section 6.1 shows in the regression, the parameters for geographical location are not significant for the outcome of aggregated profits. Taken together, the scenario 100% core is preferable to 0% core from the perspective of a firm, but we cannot draw such a clear conclusion for the variable case.

Traditionally social welfare in the literature is defined as the sum of producer and consumer surplus (see e.g. Tirole, 1988). The formal description of welfare is given in Section 4.2 and Appendix A.1. If we accept the welfare concept proposed in this work, we can draw conclusions from the analysis of consumer surplus, producer surplus and the total welfare in the scenarios. The welfare, as it is used here, gives a very aggregated picture of several important industry characteristics. Apart from prices on the different markets, consumer surplus depends on the technological

distances between existing product variants and on the number of radical product innovations since only these increase the circumference of the technology circle. The effects of process innovations are important for production cost and thus for the competition between firms. The markets determine the economic value of knowledge and the resulting profits from market interaction are the most important part of producer surplus.

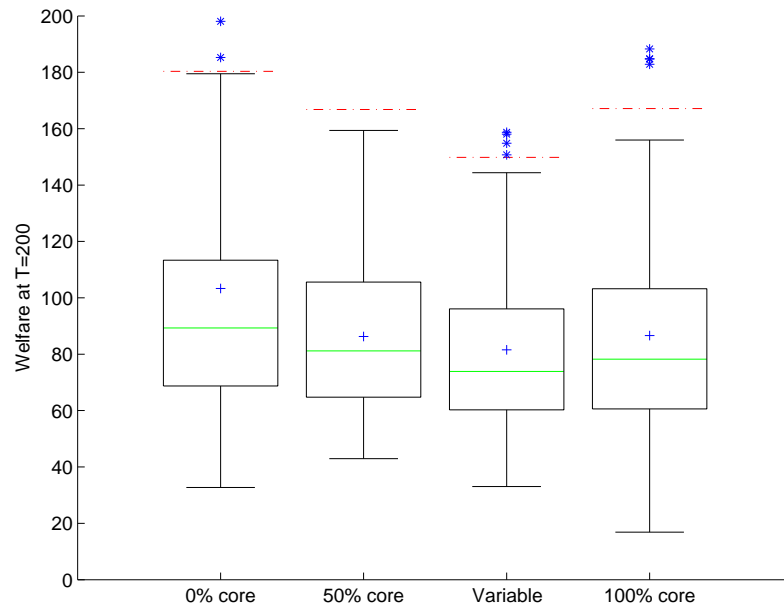


Figure 7.7: The number of firms at the core and welfare.

The outcome with respect to welfare at the end of the simulated time horizon is shown in Figure 7.7. The corresponding statistical tests in Appendix A.3 support the impression of the picture at least to a confidence level greater 90%: First, the ranking in the settings with fixed location is not obvious, but 0% core has a higher welfare than 100% core. Second, the welfare in the case with variable geographical location appears to be lowest. The results for consumer surplus and producer surplus show the same picture with the only exception that consumer surplus in 50% core lies significantly above 100% core. Further, it is worth noting that in all cases the consumer surplus, the producer surplus and welfare are increasing over time. The sorting between highest values in 0% core and lowest values for variable is also persistent over time.

Although the statistical tests of welfare indicate that there is still a high level of uncertainty left, the results point toward a negative relation between firms at the core and welfare: Welfare in 0% core is higher than in 100% core. The freedom to choose a geographical location, even with no additional sunk costs, decreases welfare for the whole industry. Welfare in the case with no learning through knowledge spillovers between firms increases mostly because more radical product innovations

positively influence consumer surplus⁸ and higher profits increase producer surplus, which could be caused by more heterogeneous knowledge of firms. Only looking at consumer surplus would not change the conclusions. These results of the theoretical model are rather surprising as several authors promote the benefits of agglomerations and local learning for the firm as well for the economy (e.g. Porter, 1998; Malmberg and Maskell, 2006).

The findings of this section could also be interpreted as a possible justification for economic policy: Economic policy should try to enforce that all firms are located either on the periphery or all at the core because both situations, according to the results of the model, would increase welfare. If all firms were located at the core, this would lead to a faster technological diffusion and more product innovations in total. The other extreme case, where no firms exchange knowledge, induces a higher rate of radical product innovations, a higher maximum level of knowledge for process innovations and higher welfare of the industry. In Section 7.3 we will try to evaluate which political measure could be useful to increase welfare. But first we have a closer look at the influence of the technological surrounding on the innovative competition between firms in Section 7.2.

7.2 Technological Regimes

One of the main questions raised by Schumpeter is: What kind of market characteristics and technological environment promotes innovations? The arguments proposed by Schumpeter do not give a clear answer. In his earlier writings the author admired small entrepreneurial firms which achieve profits from their mostly radical innovations (Schumpeter, 1912). Later on he thought that large monopolistic firms have better capabilities to push the technological frontier in small but numerous steps, which results in a better technological development of an industry (Schumpeter, 1942).

The aim of this section⁹ is to contribute to this discussion in order to get a better understanding of industrial dynamics connected with the technological development of an industry. For the purpose of this section we abstract from the influence of geographical proximity and fully concentrate on technological proximity. Thus, the assumption about learning through knowledge spillovers is given due to the characteristics of the technological regime of the industry. Firms cannot change their geographical location. As we will see, the approach in this section is a refinement of

⁸This effect seems to overweight the fact that prices in 100% core are on the average below 0% core.

⁹This section is based on Wersching (2006). Despite major changes on the demand side of the model the results for all technological regimes are qualitatively the same in both versions of the model.

the 0% core and 100% core scenarios of Section 7.1. In contrast to previous applications of the model we not only consider minor changes but alter many parameters at the same time. We compare the outcome of two settings with alternative main characteristics which correspond to two archetypes of an innovative industry.

From a policy perspective it could be of great importance to know what circumstances lead to more innovations because innovations seem to be the main source of economic growth. Knowing the mechanisms at work would allow policy makers to create appropriate measures supporting firms and public institutions. Therefore research questions which are approached in this work are: Which view of Schumpeter is right, what surrounding leads to a better technological development of an industry? What is the effect of competition in an innovative industry, is there a clear relation between market structure and innovation? And last, what is the role of knowledge spillovers, how does internal and external learning influence the technological development?

This section is closely connected to Winter (1984), where the author proposes to model and to discuss two stylized scenarios in order to get a clearer picture of the mechanisms described by Schumpeter: In the entrepreneurial regime firms rely more on external learning, the results of innovation are more stochastic and there are many entries of innovative firms in the industry. In contrast to this, the routinized regime is characterized by firms concentrating on internal R&D (innovation and imitation) and by the fact that the outcome of innovations depends on old techniques previously used in the firm. As results of the simulation study Winter (1984) shows that in the entrepreneurial regime average productivity changes more smoothly, the industry is less concentrated and less profitable compared to the routinized regime. The evolution of prices is similar in both scenarios. Other simulation models also deal with the topic of technological regimes, see Section 3.2.2.

Further, this endeavor is interesting from a methodological point of view because the outcome of our model is compared to the results of a previous simulation model, namely Winter (1984). Several scholars stress this topic in the literature under the notions of docking (the alignment of computational models (Burton, 2003)) and replication (the reproduction of earlier results (Hamermesh, 2007; Windrum et al., 2007)). This process is in particular important for agent-based simulation models (Wilensky and Rand, 2007). As Hales et al. (2003) argue, a result from simulations is then more reliable if it is reproduced many times by different modelers and re-implemented on several platforms in different places. Here we do not perform a replication of the original computational model but introduce a whole new interpretation of the conceptual model of technological regimes based on additional theoretical and empirical contributions since the seminal article. Obviously, we implemented our computational model using different hardware and software.

Our replication is successful in the way that the output is sufficiently similar to the original model, which was describes as relational alignment by Wilensky and Rand (2007). Hence, this section replicates most of the qualitatively relationships in a different conceptual and computational model which supports the earlier findings and hereby underlines the significance of the previous work by Winter (1984).

The debate on technological regimes can be tracked back to the writings of Schumpeter where the author described rather different constellations of competition and the role of innovations. In Schumpeter (1912) the author emphasized the role of small entrants who challenge the incumbents with their innovations. In the literature this scenario was named Schumpeter Mark I.¹⁰ In his later days Schumpeter (1942) almost radically changed his view to the effect that now for him large firms had better capabilities to accumulate knowledge and gain economic profits from innovations. This view was labeled as Schumpeter Mark II. In order to characterize fundamental differences in the structure of innovative conditions the notion of technological regimes was introduced. Technological regimes are defined by Nelson and Winter (1982) as the technological environment of an industry under which firms operate.

Malerba and Orsenigo (1996, 2000) propose that a technological regime can be seen as a certain combination of the following properties of technologies:

- Opportunity conditions
- Cumulativeness conditions
- Appropriability conditions and
- Type of knowledge base.

Opportunity conditions reflect the abundance of knowledge external to an industry. They express how easily a firm can successfully perform an innovation with a given amount of resources invested in research. Cumulativeness conditions define to what extent the build-up of new knowledge depends upon the knowledge already accumulated in the firm. The appropriability condition stands for the ease of extracting profits from innovation and the protection of intellectual property rights. The possibilities of imitation have a great influence on the level of appropriability. As a last characteristic the knowledge base specifies the key dimensions of knowledge relevant for innovation activities.

The nature of learning is important for innovations and can be described by the properties of technological regimes, too. Learning is here understood as knowledge transfer which can occur from institutions external to the industry to firms,

¹⁰The labels Schumpeter Mark I and Schumpeter Mark II were first used by Nelson and Winter (1982) and Kamien and Schwartz (1982).

or between and within firms of an industry. If firms have possibilities to learn from public institutions, e.g. universities, it could be argued that opportunity conditions are high. The cumulateness condition on the other hand is significant for learning within a firm. It represents the way firms can build up knowledge and how knowledge of a related technology can be transferred. These activities should represent internal knowledge spillovers. On the other hand, the appropriability conditions and the type of knowledge base are of major importance for external knowledge spillovers which are knowledge flows between firms. If knowledge circulates very easily between competitors and cannot be protected by legal authorities, the appropriability conditions of innovations are low. The degree of tacitness of knowledge, which is given by the characteristics of the knowledge base, and aspects of proximity are important for the transfer of knowledge. Altogether we see that learning is strongly connected to technological regimes.

When it comes to the debate of market structure and innovation, the ease of innovative entry in an industry is the first relevant aspect. Technological entry barriers define the competitive advantages of the incumbents over potential competitors related to knowledge and innovations (see Pavitt et al., 1989; Marsili, 2001). A highly cumulative character of knowledge, low knowledge spillover between firms and no learning from public sources may result in high technological entry barriers and prevent firms from entering a market. The question whether competition increases or decreases firms' incentive to innovate is the second aspect of market structure and innovation. After Schumpeter (1942) it was assumed that innovation would decline with competition as more competition reduces the monopoly rents that reward successful innovators. Taking this relation as true it could be argued that there is a trade-off between static and dynamic efficiency, because more innovations would occur in more concentrated industries. Empirical studies to this topic in general do not support this view. For example a recent article indicates a complex non-linear function in the form of an inverted-u shape (Aghion et al., 2005). In contrast to this Nelson and Winter (1982) argue that both variables, market structure and innovations, are endogenous to the nature of a technological regime so that the discussion on competition and innovation had better taken into account the fundamental properties of technological regimes (Marsili and Verspagen, 2002).¹¹

Beside the theoretical debate on technological regimes, empirical works try to indicate regularities which characterize certain properties of technological regimes in different industries (see e.g. Pavitt, 1984; Pavitt et al., 1989; Audretsch, 1991; Malerba and Orsenigo, 1996; Breschi et al., 2000; Marsili, 2001; Marsili and Verspagen, 2002). For example Malerba and Orsenigo (1996) study six countries (D, F, GB, I, USA, J) and 49 technology classes. They find evidence that 19 technological

¹¹See also Cohen (1995) in this context.

classes (including mechanical technologies and traditional sectors) indicate patterns of Schumpeter Mark I and 15 technological classes (including chemicals and electronics) could have been characterized as Schumpeter Mark II. The results within each technology class have been remarkably similar across all countries.

The dynamic perspective of the simulation model enables the analysis of the technological development of a horizontally differentiated industry. Knowledge is seen as the major factor driving the technological development and can be used by firms for process and product innovations. Another merit of the model is that it allows an analytical description of the learning processes through knowledge spillover between and within firms. These features are needed to represent technological regimes in a computational model. The differences between the Schumpeter Mark I and Schumpeter Mark II scenarios and their representation in the model are summarized in Table 7.1 and the corresponding parameters are given in Table A.4 in the appendix.

	Schumpeter Mark I	Schumpeter Mark II
External Institution	Yes	No
Process Innovations	Low Investments	High Investments
Product Innovations	Easier and more radical	Higher thresholds and mostly incremental
Initial Knowledge for new Technologies	Non-Cumulative	Cumulative
Patent Length	Short Patent Protection	Long Patent Protection
Knowledge Spillover	High external and low internal Spillovers	No external, but high internal Spillovers
Number of Firms in the Industry	Many	Few

Table 7.1: The representation of technological regimes in the model.

In the Schumpeter Mark I (or entrepreneurial) regime the sources of knowledge are mainly external to the firm. Beside high knowledge spillovers from competitors firms learn from an institution which is understood to be external to the industry. The institution provides and extends knowledge in existing technologies and all firms can benefit from its technological advances. The amount of knowledge transfer from the institution to the firms depends on each firm's absorptive capacity. Examples of external institutions occur every time when researchers or firm representatives from other industries meet firm representatives from this specific industry, e.g. in univer-

sities, at think tanks, exhibitions or conferences. For simplicity it is assumed that the investments for the external institution are funded by public authorities. Imitation between companies is the second source of external learning. High opportunities for imitation and a short patent length result overall in low technological barriers to entry. Entry in new markets is possible after only one period and the high level of external knowledge spillover allows fast catch-up to technological leaders in the sub-markets. The industrial environment is characterized as 'creative destruction' because the thresholds for incremental and radical product innovations are lower than in the other scenario. The industry is less concentrated because there are more firms in the industry and each sub-market is initialized as a duopoly so that every firm faces a direct competitor in their main market. Although the industry has a fixed number of firms the market structure on every sub-market is determined endogenously as firms can enter and exit markets.

The Schumpeter Mark II (or routinized) regime, which is sometimes described as 'creative accumulation', is in contrast characterized by large established firms. This fact is represented in the way that the industry consists of fewer firms which start as monopolists on one sub-market. The main sources of knowledge are seen internal to the firm with high investments in process innovations and high knowledge spillover within the firm, where knowledge from one technology is used to gain new knowledge in another technology. There exists no public external institution. The thresholds for product innovations are higher, so that on the average more knowledge is needed to achieve a product innovation. Altogether there are high technological barriers to entry in the Mark II scenario resulting from the long patent length and the absence of external learning. This fact is underlined by the cumulative structure of knowledge. A successful product innovation is initialized in the way that the starting level for process innovation depends on the knowledge of the innovating firm in neighboring technologies.

While comparing these two stylized scenarios it is important to note that other aspects are not varied in the two technological regimes. Among them are strategies, capabilities and resources of the firms as well as the technological space at start (which means that the technological specialization of firms and industry is equal, too) and the preferences of the consumers. Firm strategies stay constant but the technological space changes endogenously as the industry evolves.

For the formal representation of the technological regimes several changes in the description of the model have to be made. The knowledge build-up process in the external institution works similar to the knowledge accumulation of the firms. The knowledge stock $RD_{j,t}^{ext}$ is increased by public investments $I_{j,t-1}^{ext}$ analogously to

equation (4.1):

$$RD_{j,t}^{ext} = 1 - (1 - RD_{j,t-1}^{ext}) \frac{1 + \alpha^{ext} \cdot \beta^{ext} \cdot I_{j,t-1}^{ext}}{1 + \alpha^{ext} \cdot I_{j,t-1}^{ext}} \quad (7.1)$$

Firms (at least in the Schumpeter Mark I scenario) can use public knowledge but the knowledge spillovers from the external institution $SP_{i,j,t}^{ext}$ again depend on the firm's capabilities to exploit knowledge analogously to equation (7.3). As internal and external knowledge spillovers and spillovers from the external institution are understood to be perfect substitutes, the later form $SP_{i,j,t}^{ext}$ has also to be considered for the knowledge build-up in equation (4.1) and is given by:

$$SP_{i,j,t}^{ext} = \omega^{ext} \sum_l \left[\frac{1}{1 + d_{j,l,t}^{tech}} \cdot t_{jl,t} \cdot e^{-\frac{t_{jl,t}}{\gamma_{i,t}}} \right] \quad (7.2)$$

Apart from the usage of a external institution the two technological regimes make use of a changed formalization of knowledge spillover. Here, the different types of spillovers in equation (4.10) are weighted with the new parameters ω_{ex} and ω_{in} . Thus, the previous formula for spillovers changes to:

$$SP_{i,j,t}^{proc} = \omega_{ex} \cdot \sum_{l=1}^{m_t} \sum_{k \neq i} \left[(1 - d_{i,t}^{geo})(1 - d_{k,t}^{geo}) \cdot \frac{1}{1 + d_{j,l,t}^{tech}} \cdot t_{ik,jl,t} \cdot e^{-\frac{t_{ik,jl,t}}{\gamma_{i,t}}} \right] \\ + \omega_{in} \cdot \sum_{l=1}^{m_t} \left[\frac{1}{1 + d_{j,l,t}^{tech}} \cdot t_{ii,jl,t} \cdot e^{-\frac{t_{ii,jl,t}}{\gamma_{i,t}}} \right] \quad (7.3)$$

In the following the model is analyzed with respect to technological development, main industry characteristics and learning through knowledge spillover. All graphs are based on 100 simulation runs in the described settings. In most cases the two stylized technological regimes are compared with the arithmetic mean over all runs. Apart from the graphical presentation the results are underlined with Wilcoxon rank sum tests in Appendix A.3. The outcome of the simulation studies, which is going to be discussed in the following part, appears to be highly significant as all null hypotheses can be rejected to a confidence interval greater than 99%.

In contrast to the model of Winter (1984) the number of sub-markets in the industry is not constant. The industry is initialized with a fixed number of sub-markets and every additional variant represents a successful introduction of a new product. Results yield that the number of product innovations is quite similar for both types of technological regimes. The thresholds for product innovations are first reached by firms in Schumpeter Mark II although more knowledge¹² is necessary to

¹²See parameters a , b and c in Table A.4.

introduce a new product variant. As the industry evolves, the number of product innovations is growing faster in Schumpeter Mark I. It is interesting to note that in the short-run there are on the average earlier and more product innovations in Schumpeter Mark II whereas later on the number of markets in total is higher in Schumpeter Mark I. But this only happens as the simulations continue after the 200 periods typically considered in the other experiments.

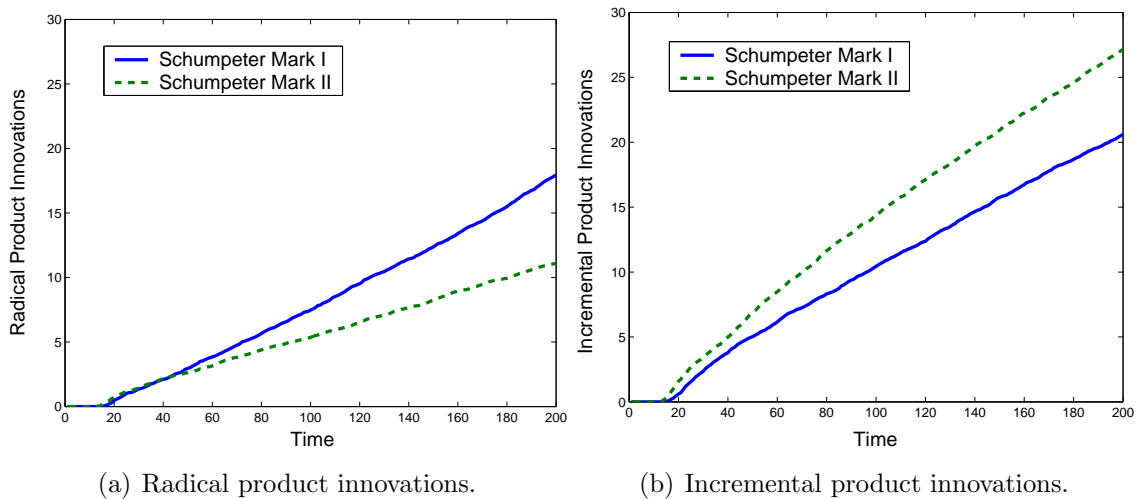


Figure 7.8: Technological regimes and the outcome for radical and incremental product innovations.

Apart from the number of product innovations there exists a structural difference in the type of product innovations. In order to show this effect, Figure 7.8 draws graphs of successful radical and incremental product innovations over time in the two technological regimes. The figure indicates that there are far more radical product innovations in Schumpeter Mark I and more incremental product innovations in Schumpeter Mark II. This result is driven by the assumption that product innovations are easier and more radical in Schumpeter Mark I. Despite the similar number of product innovations the technological space changes in Schumpeter Mark I much more radically. Whereas in Schumpeter Mark II firms compete with more technologically close product variants with limited demand, firms in Schumpeter Mark I benefit from new consumers which are attracted to the industry through radical product innovations. There seems to be more competition *between sub-markets* than competition *in sub-markets* in Schumpeter Mark II.

Process innovations complete the picture of the technological development of the industry. Like Winter (1984) the scenarios are analyzed with best-practice and average values for process innovations over all firms and sub-markets. Figure 7.9 captures the evolution of the first 100 periods on the level of best-practice (a) and over 200 periods for the average productivity (b).

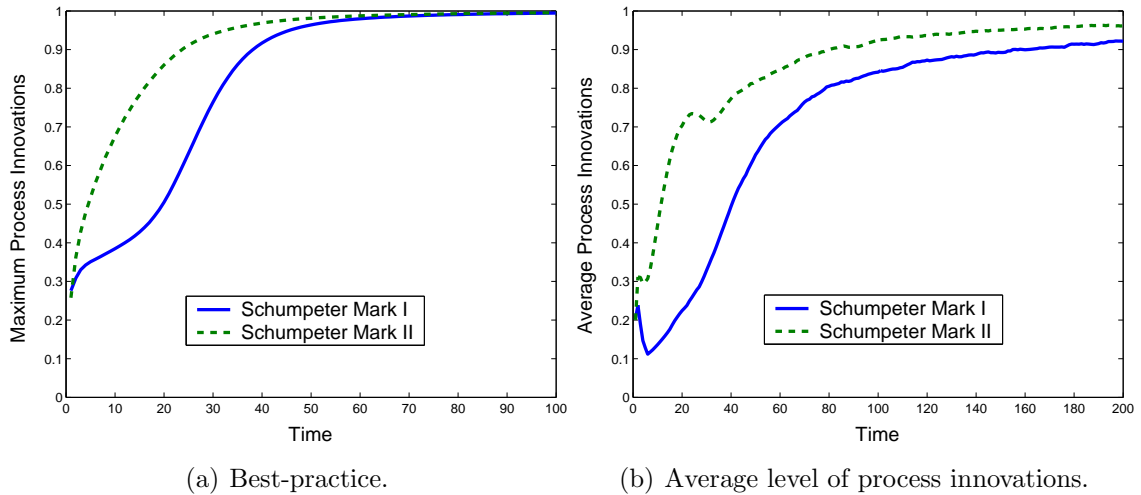


Figure 7.9: Technological regimes and process innovations.

In all cases the industry starts around $RD^0 = 0.2$. The best-practice for process innovations is rising fast in Schumpeter Mark II. Firms in Schumpeter Mark I seem to take some time, but after that the steep curve stands for a very fast development of the best practice. One explanation for this pattern could be the low absorptive capabilities at the beginning of the simulation runs. Because of this Schumpeter Mark I firms at first have problems absorbing external knowledge but, as shown in the graph, once the critical level of absorptive capacity is reached the best-practice increases very fast. However, firms in Schumpeter Mark II invest in internal R&D and in this setting the technological frontier develops at a greater pace.

In the evolution of the average knowledge for process innovations firms in Schumpeter Mark II show better outcomes. Two interesting effects can be seen in the right figure: First, at the beginning the average level of process innovations is reduced as more technologically lagging firms enter sub-markets in Schumpeter Mark I. In Schumpeter Mark II this does not occur, possibly because high technological entry barriers prevent many firms from penetrating sub-markets. Second, after the first wave of new product variants there is a slowdown in the Schumpeter Mark II curve around period 30. This might result from the cumulative structure of knowledge for new technologies because at this time the first product variants are initialized at a lower level of knowledge. In the long run the lead of Schumpeter Mark II firms in terms of process innovations persists but the difference is continuously reduced.

Summing up, the simulation study shows that the technological development is better in an industry that is characterized by Schumpeter Mark II conditions. The situation for process innovations is obvious because here the development of the best practice is faster and firms do in average have lower production cost. In terms of product innovations there is a shift from early successful firms in Schumpeter

Mark II to more innovative firms in Schumpeter Mark I in the long run. But taking the lower number of firms that innovate in Schumpeter Mark II into account, the technological development in terms of number of product innovations per firm could be interpreted as superior to the other scenario, too.

The findings for the technological development are in line with the simulation results of Winter (1984). Further, in the model by Winter (1984) the outcome for the main industry characteristics is the following: The industry is less concentrated and less profitable in the Schumpeter Mark I regime and prices are similar in both scenarios. The interpretation of technological regimes in this paper only partially reproduces these findings. First, it can be shown that the average profitability is indeed higher in Schumpeter Mark II. Second, in contrast to Winter (1984) prices appear not to be equal but lower in the Schumpeter Mark I scenario. And third, for aspects of concentration evidence is mixed.

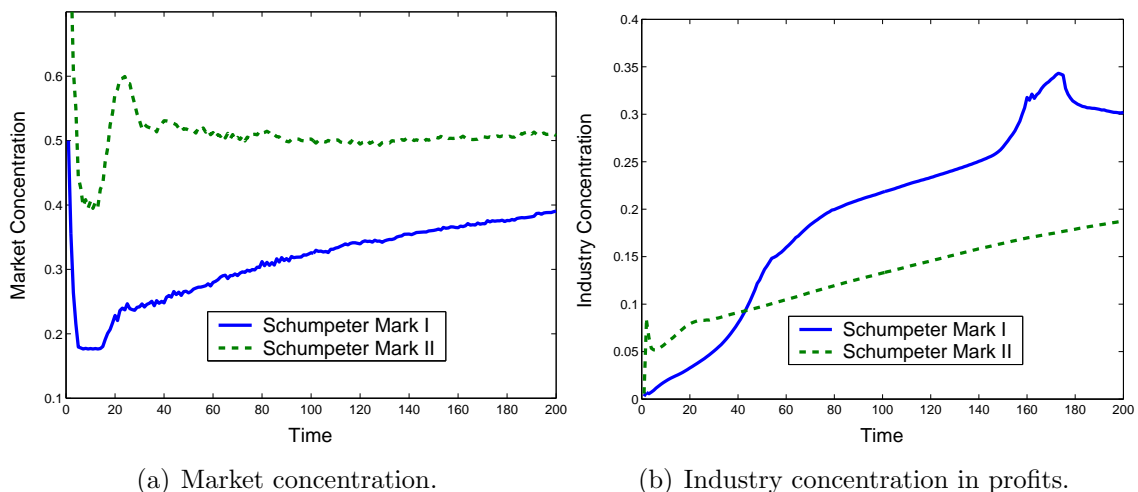


Figure 7.10: Technological regimes and measures of concentration.

In Figure 7.10 two forms of concentration are demonstrated: The average concentration of quantities on markets (a) and the average concentration of the whole industry given by aggregated profits (b). Both variables are calculated as a Herfindahl index, whereas industry concentration is normalized between zero and one because of the different number of firms in the scenarios. Market concentration is therefore given by $H = \left[\frac{\sum a_i^2}{(\sum a_i)^2} \right]$ with $a_i = x_{i,j,t}$, and analogously industry concentration by $H = \left[\frac{\sum a_i^2}{(\sum a_i)^2} - 1/n \right] \cdot \frac{1}{1-1/n}$ with $a_i = \sum_t \Pi_{i,t}$.

It is interesting to see that in both technological regimes market concentration rapidly falls to lower values at start and with the first introduction of new products market concentration jumps to a higher level. In Schumpeter Mark II the high technological entry barriers enable the innovating firm to stay as a monopolist on new markets. But because the average market concentration in Schumpeter Mark

II is still much below 1, firms enter open markets despite the difficulties. The low technological entry barriers in Schumpeter Mark I lead to fast entries in new sub-markets so that the market concentration is much lower. This result was also obtained by Winter (1984). As the industry evolves, more incremental product innovations reduce the demand for each product variant. The number of active firms on established sub-markets goes down because fewer firms can be profitable. Because of this market concentration is rising in Schumpeter Mark I. In the long run both curves seem to converge as market concentration in Schumpeter Mark I increases at a greater pace but at $T = 200$ market concentration in Schumpeter Mark II is still higher.

The industry concentration measures how equally the aggregated profits are distributed over all firms in the industry at a certain point of time. During the first periods firms in Schumpeter Mark II differ more. But after the first product innovations the curve for Schumpeter Mark I is much steeper, which leads to higher industry concentration in the longer run. The high value for Schumpeter Mark I is surprising because the structure of knowledge is less cumulative. The absorptive capacity could be an explanation for the strongly increasing difference in aggregated profits because firms with low absorptive capacity cannot use external learning opportunities and are therefore less profitable. Over time industry concentration increases in both cases. This means that previously successful firms become more successful showing a strong separation between technologically leading and technologically lagging companies.¹³ This effect is even stronger for firms in Schumpeter Mark I.

If we accept the view that the technological development of an industry stands for dynamic efficiency and the development of prices, profits and market concentration for static efficiency¹⁴, then the findings of the simulations could point at a trade-off between static and dynamic efficiency. Industries with conditions similar to Schumpeter Mark II may show more innovations and lower production costs. On the other hand, this is associated with monopolistic tendencies in the form of higher prices, higher profits and higher market concentration. It is important to add that in the long run the Schumpeter Mark I scenario shows more and more radical product innovations. High profits only lead to a better technological development when firms concentrate on internal research activities and, thus, high profits in Schumpeter Mark I would not provoke innovations to the same degree because firms are more focussed on external learning.

The formulation of knowledge stocks which are located on a circular technological

¹³In the literature the effect is sometimes described as 'success breeds success' (e.g. Malerba and Orsenigo, 2000).

¹⁴Of course there is nothing to say about efficiency while comparing two economic examples. These terms are used in the literature to define the outcome or process of competition (see e.g. Blaug, 2001).

space allows a representation of the firms' technological portfolio. For every firm it is possible to analyze the height and location of the knowledge stocks. In this context it is feasible to measure firm specialization which takes into account the properties of knowledge. A specialized firm has high peaks which are located close to each other, and a not specialized (or diversified) firm has peaks which are equally high and uniformly distributed over the circular technological space. Both types of specialization are calculated with a normalized Herfindahl index, one for the height of knowledge and one for the location of knowledge. The closer the index is to 1, the more specialized are the firms on the average, see Section 6.1 for the definition of specialization.

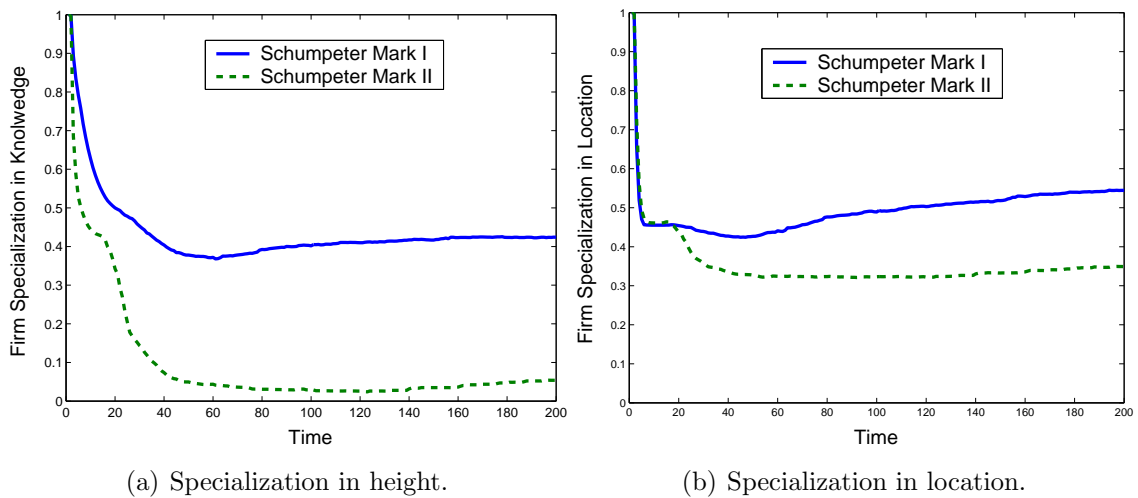


Figure 7.11: Technological regimes and firms' specialization.

Figure 7.11 shows the average values over all firms for both forms of specialization. All curves start at 1 for maximal specialization because each firm is initialized with knowledge in exactly one technology. In the first phase of the simulation firms gain knowledge in other technologies as they enter sub-markets and invest in R&D or learn. Again the introduction of first product innovations has a major influence on the curves leading to more diversified firms, especially in Schumpeter Mark II. Both graphs of Schumpeter Mark II seem to converge to a low level of specialization whereas the graphs for Schumpeter Mark I keep increasing as time goes by. The interpretation of the picture is obvious: Firms in Schumpeter Mark I are (after an initial phase) on the average more specialized in terms of height as well as location of knowledge in the technology space.

The result of higher firm specialization in Schumpeter Mark I is rather surprising and tests with different parameters (e.g. number of firms or other forms of knowledge build-up in the public institution) suggest that this result is quite robust. Knowledge and technological progress in Schumpeter Mark II are strongly cumulative at

firm level. Hence, one would expect highly specialized firms because knowledge is best transferred through internal spillover with similar peaks located close to each another. In contrast to this the sources of knowledge in Schumpeter Mark I are very diversified resulting from the external institution and imitation from competitors. Firms do have very broad opportunities to learn and one would expect more diversified firms in Schumpeter Mark I.

In order to explain this finding three possible arguments could be of relevance. First, it could be the case that the scale of learning and R&D projects is much smaller in Schumpeter Mark I and so firms can only develop knowledge in and around their starting point. Second, investments in R&D could lead to more diversified firms and external learning could generate more specialized firms under the described circumstances. And third, the scenario of 'creative destruction' could have significant influence on the technology space resulting in more specialized firms. These arguments should be discussed in detail.

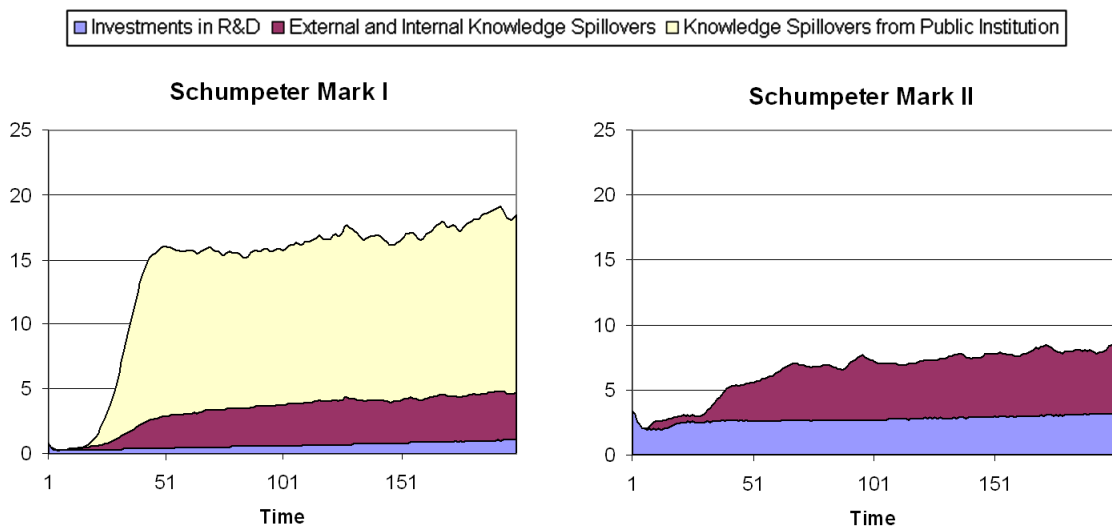


Figure 7.12: Sum of learning from different sources in the technological regimes.

For the generation of knowledge firms use investments in R&D, internal learning, imitation from competitors and learning from the public institution. All elements are understood as perfect substitutes to create knowledge. Figure 7.12 presents the sum of investments in R&D and all types of knowledge spillover for process innovations to see if the scale has an impact on the high level of firm specialization in Schumpeter Mark I. In Schumpeter Mark II only 5 instead of 10 firms exist in the industry. The graphs show that the sum of R&D and knowledge spillover in Schumpeter Mark I is (after an initial phase) at least twice as high. Hence, a firm in Schumpeter Mark I benefits from R&D and learning on the average at least as much as a firm in Schumpeter Mark II. Additionally this is supported by evidence that the

level of absorptive capacity evolves equal in both scenarios. Therefore the amount of learning and a possible shortfall of absorptive capacity cannot be the reason for high specialization of firms in Schumpeter Mark I.

The second argument debates not the scale but the structure of the acquired knowledge. Firms in Schumpeter Mark II can create knowledge very fast in selected technological areas because investments in R&D do not rely on the existing level of knowledge. On the contrary, knowledge spillovers depend on the gap between the specific knowledge stocks. In Schumpeter Mark I firms may have less influence on the technological areas they want to improve. Instead they rely more on the external technological development. Because of this, it could be argued that R&D activities are more focused and guided. Firms in Schumpeter Mark II have more freedom to change their temporary technological emphasis with high investments in R&D. Firms can enter profitable sub-markets having in mind that high investments in process innovations allow a fast catch-up to the incumbents independent of the current knowledge in this technology. As a second option higher profits in Schumpeter Mark II lead to higher investments in product innovations and more successful product innovations (per firm) can be conducted next to profitable markets. More product innovations in technologies which have so far not been known to the firm cause more diversified firms in Schumpeter Mark II, too. Although learning possibilities in Schumpeter Mark I are very broad, firms appear to absorb only technologically close knowledge and this generates much more specialized firms. Indeed, the structural difference between more guided investments in R&D and less controlled external learning may be a reason for more diversified firms in Schumpeter Mark II.

The technological regime of Schumpeter Mark I was characterized as 'creative destruction'. This view can be supported by Figure 7.8 a), which shows that the number of radical product innovations are much higher in Schumpeter Mark I. Every radical product innovation distorts the technological space because it separates two previous technologies and the technological circle is expanded. The technological distances between technologies increase and it becomes more difficult to learn in distant technological areas. Firms in a rapidly changing technological space caused by more radical product innovations have difficulties to keep a diversified technological portfolio. Therefore, major changes in the technology space could be another explanation for the higher firm specialization in the scenario of Schumpeter Mark I.

Taken together this section supports the empirical finding that the technological environment of an industry has a fundamental impact on the competition and technological development of a industry. Here, the changes in the properties of technological regimes, as proposed by Malerba and Orsenigo (2000), reproduce most of the earlier results by Winter (1984) and additional conclusions can be made upon the emerging type of product innovations and firms' specialization. Section 7.3 will

continue with the question whether and how public policy might influence the pre-conditions for the innovative competition between firms.

7.3 Evaluation of Policy Measures

This section discusses whether and how public policy may influence the outcome of the virtual industry. Starting from the standard case of the industry it is argued that there is room for steering by a superior authority. Four potential aims of regional innovation policy are introduced and their impact and costs are quantified with the help of the simulation model.¹⁵

7.3.1 Regional Innovation Policy in the Model

Before going into the analysis of concrete policy measures in the simulated industry, one has to ask about the rationale for policy. In an insightful survey by Metcalfe (1995) the author distinguishes two major approaches in the debate about innovation and policy: The equilibrium oriented Neo-classical and the evolutionary school of thought. Both theories provide a normative foundation for economic policy; this work borrows ideas from both concepts.

On the one hand, the traditional economic theory is based on the notion of so-called market failures which prevent economic agents to find a Pareto optimal equilibrium. Typically the market failures violate one or more conditions for perfect competition. Thus, the market mechanism will not lead to the best possible allocation of resources on different tasks and agents. Metcalfe (1995) mentions the following examples of market failures, which according to Dosi (1988b) are crucial in the context of innovation: Indivisibilities in the process of knowledge production, uncertainty of the innovative outcome, information or knowledge asymmetries, market power as a consequence of innovation, (partial) public good character of knowledge, and externalities in the form of knowledge spillovers. The aim of politicians in the Neo-classical framework is the maximization of a social welfare function which depends on the personal welfare maximizing behavior of firms and consumers. The policy maker is understood to be fully informed and knows how to identify and implement the optimum.

The seminal article for the justification of an innovation policy in an equilibrium model is Arrow (1962). The author compares the potential profits from a cost-reducing process innovation in a monopolistic and competitive setting. In the latter case it is assumed that the firm may become a monopolist itself if the cost reduction is high enough. Market demand and the cost for the innovation are the

¹⁵Parts of this section are also published in Wersching (2007b).

same in both situations. With these assumptions the incentive for an innovation is lower for a monopolist than for one of the competitive firms because the monopoly power and profits before the innovation act as a strong disincentive to further innovative endeavors. The most significant result from a policy perspective is the fact that a social planner has even higher innovative incentives than a monopolist or one of the competitive firms. Therefore, in the view of Arrow (1962) competition enhances incentives to innovate, which is similar to the early writings of Schumpeter (1912). Another seminal work which compares innovation in a social optimum with a competitive situation is proposed by Dasgupta and Stiglitz (1980). In this Cournot oligopoly model with R&D all profits are competed away as firms can freely enter the market. The main finding highlights the role of an endogenous market structure which is determined by market demand and innovation possibilities. Thus, both the degree of concentration and the nature of innovative activity emerge endogenously but no causal link can be established between them. The market equilibrium is not characterized by an optimum allocation of resources as there might be under- or over-investment in R&D.

In Metcalfe (1995) the traditional welfare approach was criticized as not being dynamic and not considering information asymmetries. The importance of knowledge spillovers especially is emphasized as follows: *".. in a world of symmetric firms, spillovers are logically impossible. [...] Asymmetries have their proper role in a dynamic framework not an equilibrium one."* (pp. 446-447, Metcalfe, 1995). These arguments are of course similar to the discussion whether equilibrium or simulation models are better suited to represent innovation and proximity, see Chapter 3. The acceptance of heterogeneity as a crucial assumption in the innovative competition between firms brings us to the evolutionary perspective of economic policy.

The evolutionary approach to technical change tries to explain why technological competition is seen as the driving force behind structural change and economic development. Central aspects in this framework are the diversity of behavior of agents, the relevance of process and change - not equilibrium and state, the fact that the mainspring of profit opportunity is the possession of privileged knowledge, and that bounded rationality also counts for policy makers. As Teubal (1997) argues, the goal of evolutionary policy is not to abandon the market-failure analysis but to set it into a wider context which incorporates aspects of dynamics and uncertainty. The main goal for evolutionary policy is the stimulation of innovations taking into account that policy may sometimes fail (Metcalfe, 1995; Werker, 2006). There is a wide agreement on this aim of evolutionary policy but it is highly debated how this goal can be achieved.

Tödting and Trippl (2005) propose good reasons why evolutionary policy should be implemented at a regional level (see also Chapter 2 and Scott and Storper (2003)):

First, regions differ in their technological specialization and innovative performance more than nations. Second, knowledge spillovers are understood to occur on a regional level. Third, the exchange of tacit knowledge requires personal contact and trust, which are both favored by geographical proximity. And fourth, policy competencies and institutions can often be more easily influenced at a regional level. The application of an evolutionary policy to the regional level should be called **regional innovation policy**. We therefore adopt the view of Tödtling and Trippl (2005) who assert that regional innovation policy is based on concepts of the new endogenous growth theory, the cluster approach, the knowledge economy and the literature on knowledge spillovers.¹⁶ The main characteristics of a regional innovation strategy can be seen in the focus on the creation and exchange of knowledge in geographically concentrated industries.¹⁷

Having defined regional innovation policy we can now ask when such a policy can be successful and why we might need political intervention in the model proposed in this book. Metcalfe (1995) argues that economic policy should not subsidize firms for activities they would otherwise carry out themselves. In the context of policy measures to support a cluster in a specific region Brenner (2004) discusses three possible outcomes of policy: First, a cluster might emerge that would have also come up without the policy. Second, a cluster might emerge that would not have come up without the policy. And finally, no cluster might emerge. The first and third point indicate political failures because economic resources are wasted or do not lead to the desired outcome. Only the second possibility is socially desirable and can be seen as an effective policy. Furthermore, the author concludes that policy should only choose regions with a high likelihood that a cluster will emerge. Once the cluster exists, Porter (1998) advocates an upgrading of every type of cluster and he warns that policy should not distort the competition between firms.

In the model of Chapter 4 firms might choose a location at the core or cluster where they might benefit from local externalities in the form of knowledge spillovers. The justification for regional innovation policy in the model can be seen in the fact that scenarios other than standard, which can be interpreted as left-alone or free-market scenarios, show better outcome for technological development and welfare, see Section 7.1. Hence, the market solution is regarded to be inferior to special cases like all firms at the core or all firms on the periphery. We do not know the social optimum of this model and in the previous sections we argue that there might not

¹⁶Relevant literature for the new endogenous growth theory is Lucas (1988); Romer (1986, 1990), for clusters Porter (1998); Asheim and Gertler (2005), for the knowledge economy Nonaka and Takeuchi (1995); Cooke and Leydesdorf (2006) and for knowledge spillovers Jaffe et al. (1993); Audretsch and Feldman (1996b). These topics are discussed in detail in Chapters 2 and 3.

¹⁷A distinction between high-tech and low-tech industries or firms is counterproductive in this context (on this point see also p. 33 in Porter, 1998).

exist an ideal social optimum because there is a trade-off between maximum and average outcome for innovations.¹⁸ We think that political influence might improve the outcome of the standard case in terms of process and product innovations as well as welfare of the industry. Though the argumentation is similar to policy justifications in equilibrium models like Arrow (1962) or Dasgupta and Stiglitz (1980), we evaluate policy interventions by their impact and cost without aiming at an ideal social optimum. Furthermore, we concentrate on policies which can be analyzed in the model and which are discussed in the (mostly empirical and descriptive) literature on regional innovation policy.

In the following we mention those aspects we are not able to address in the current form of the model. First, we cannot provide arguments whether innovation policy should be maintained at a national or regional level. Second, we are further not able to discuss any other form of a local externality than knowledge spillovers - may it be positive or negative. Examples of other forms of local externalities are cost of scarce resources in a cluster, local benefits from job-markets, local social or institutional networks, and specialized input factors for firms in an agglomeration. Third, as we consider only one cluster we cannot debate processes of convergence between regions or clusters. We concentrate on the effects within an industry and can talk about convergence or divergence between firms but not between regions.

The reason why all these aspects are not modeled is that we focus on the impact of geographical and technological proximity on innovative competition, build-up of knowledge, and firm heterogeneity. Additionally, localized learning in the horizontal dimension between direct competitors is highlighted. We refer to the influence of the endogenous technological development on the demand and on other industry characteristics like concentration, prices and degree of specialization of firms, locations or industry. Therefore, the analysis concentrates on selected political measures which in the literature are understood to have a positive influence on the technological development of an industry and which can be addressed in the model. The chosen policies are enumerated in Table 7.2.

In the following we bring forward the argument why those policies are relevant for regional innovation policy, in which way they can be implemented, and how the potential cost can be estimated.

Enhance Incentive for Agglomeration

The first policy measure is connected to the positive learning externality in the agglomeration: The more firms choose their location at the core, the higher in general is the amount of spatially bounded learning through knowledge spillovers. Thus, a

¹⁸Only looking at the welfare function as given in equation (4.16) would indicate the 0% core scenario as the best of all considered scenarios, see Figure 7.7.

Policy	Name	Dimension	Measures
1	Enhance Incentive for Agglomeration	Number of Firms at the Core	Local Public Research, Funding of Cluster Firms
2	Foster Learning through Knowledge Flows	Level of Knowledge Spillovers	Public Research, Local Knowledge Networks
3	Increase Appropriability	Firm Profits	Patent Length, Consumer Budget
4	Control Specialization of Agglomeration	Specialization of Agglomeration	Funding of private R&D (first Process then, Product Innovations)

Table 7.2: Policy measures in the model.

regional authority should try to promote the attractiveness of the agglomeration so that more firms of the industry settle in the cluster. In the literature the argument can be found in several theoretical and political works: Audretsch (1998); Rallet and Torre (2000); Brenner (2004); Andersson et al. (2004); Torre and Rallet (2005); Tödttling and Trippel (2005). The relevant dimension for this kind of policy is the number of firms at the core. In the model the attractiveness of the agglomeration can be increased by two options: Either by adding local learning opportunities or by funding of cluster firms.

We model the political activity such that we come back to the concept of an external institution. The external institution provides the industry with additional knowledge funded by public investments. A formalization was already done in Section 7.2 and the knowledge build-up process is described in equation (7.1). Since the political goal is to enhance the attractiveness of the core, only firms at the core should profit from the local knowledge spillovers of the external institution (see equation (7.2)).

The second way to influence firm behavior is a subsidy to all firms that choose a location in the cluster. The formalization is equal to the introduction of additional cost at the core, see Section 6.2. Instead of bearing these costs of scarce resources firms now receive an additional payment from the regional authority in order to bind them to the agglomeration. This payment is of course taken into account in the evaluation function for the geographical location. See Appendix A.2 for further information.

The cost for this kind of policy is the sum of all public investments in the local

external institution and the sum of direct funding to all cluster firms.

Foster Learning through Knowledge Flows

The second policy aims at a general increase of the learning possibilities inside and outside the cluster. On the one hand, policy can support public research similar to the science-based industry in Nelson and Winter (1982). All firms might benefit from the knowledge produced by external institutions and this should enhance the technological development of the industry. On the other hand, spillovers inside the agglomeration are another major factor for learning between firms. A very popular piece of advise for regional innovation policy is to establish and extend networks between firms in order to enhance the exchange of knowledge. Thus public research and cluster networking are seen as appropriate methods to increase learning in a region. There are many references supporting this thesis: E.g. Lundvall and Borras (1997); Teubal (1997); Maskell and Malmberg (1999); Nauwelaers and Wintjes (2002); Andersson et al. (2004); Brenner (2004); OECD (2005); Tödtling and Trippel (2005). The relevant dimension for learning in the model is the level of knowledge spillovers. The goal of the second type of policy is to raise the level of knowledge spillovers between firms and from the public institution to all firms.

In contrast to the previous policy, which wants to attract firms to the core, the external institution in this case is not local. Hence, all firms are able to benefit from the experiences of the public research projects as this increases learning most. One can debate whether this assumption does not contradict the assumption of local learning which is central to this approach. Another interpretation of the external institution is that the government performs R&D projects directly with every firm independent of their current location. The marginal costs for such a co-operation are negligible in comparison to the costs for creating the knowledge of the external institution. In that case learning happens at a local level but is not bounded to the concept of core and periphery and the costs can be estimated with the investments in the knowledge build-up. The public knowledge is equal for all firms, but the learning outcome is obviously driven by the absorptive capacity of each firm. The relevant equations for the external institution are equations (7.1) and (7.2) and the benefits from the improved network between the firms can be represented with an increase of the height parameter ω_{ex} of external knowledge spillovers in equation (7.3).

The costs for the second policy are the sum of investments in the public institution and the cost for networking between firms. The first part of the cost function is easy to calculate but it is more difficult to estimate the learning improvements through networking which lead to higher external knowledge spillovers. These higher external knowledge spillovers are perfect substitutes to direct investments in R&D,

see equation (4.1). Therefore, we assume that costs for improving learning between firms in the cluster are the same as their additional outcome for external knowledge spillovers. Of course in reality the policy would not be that effective in the way that every Euro spent for networking directly increases learning in the same amount but we use it as a rough estimation of the political expenses.

Increase Appropriability

The next type of policy emphasizes the role of economic profits from successful innovations. The R&D investments of the firms have to be refunded through an improvement of the market position of the innovating firm. Only if the economic payoffs of innovations are high enough will a company invest in risky R&D projects (Levin et al., 1987). The benefits of innovation are summarized under the term appropriability. Following Malerba and Orsenigo (1996, 2000) the appropriability condition of an industry stands for the ease of extracting profits from innovation and the protection of intellectual property rights, see also Section 7.2. The ease of extracting profits from innovation is influenced by demand conditions in combination with patents which assure the protection of intellectual property rights. In the literature on innovation and innovation policy the importance of the demand side for innovations and the relevance of intellectual property rights is stressed: E.g. Schumpeter (1942); Rosenberg (1982); Porter (1990, 1998); Brenner (2004); Lambooy (2005). Firm profits are the indicator for the success of policy aiming at appropriability. An increase of profits in this model directly heightens the investments for process and product innovations. Hence, the goal of this policy is to increase the profits of innovating firms.

The payoffs from innovations and the demand side can be affected by political interventions in the model. By assumption a firm enjoys a temporary monopoly for each new product variant for a certain time, see Section 4.1.1. Despite the fact that no other firm can enter this sub-market for τ periods, the setting of prices is limited by the prices and technological distances to the neighboring product variants. But during the so called patent length the innovator does not have to fear a direct competitor on the new sub-market. A first policy to increase appropriability is therefore the extension of the patent length: The longer a patent is valid, the higher the payoffs from successful product innovations. As mentioned before the appropriability depends on the demand setting of the industry. Hence, the second part of this policy supports either all or a specific group of consumers. For simplicity we model this in the form of an increase of the individual demand parameter B_m , see Section 4.2. This means that the budget of all consumers is subsidized by the government. No differentiation between groups of consumers is made because they only differ in their technological preferences. From the setting of the model the in-

crease of patent length favors product innovations whereas the effect on the demand side has an impact on the payoffs from both product and process innovations.

As the patent length has already been established in the standard setting of the model, we assume that there are no significant additional costs for changing the legal system. The mechanisms to ensure the protection of intellectual property rights do not change - they only work for a longer time. On the other hand, the subsidies for consumers can be quantified in the model as the difference between politically influenced and standard budgets.

Control Specialization of Agglomeration

The last type of policy sets priority to the technological specialization of the agglomeration. This topic is also connected to the question whether a specialized or diversified environment creates more knowledge spillovers (see Section 2.3) and the change of technological specialization over the industry life cycle (see section 6.3). Approaches in the regional innovation policy tend to point toward a different role of policy at different stages of the development of a region. For example Tödting and Tripl (2005) argue that metropolitan regions are often characterized by fragmentation of the knowledge base whereas old industrial regions are often over-specialized and suffer from a lock-in to mature technologies. Both characteristics could work as barriers for innovation and innovation policy should try to countervail them. Therefore, during initial periods policy may encounter the fragmented knowledge of the firms in order to form some kind of knowledge core competencies of the agglomeration because this would increase the benefits from local learning. As the industry evolves, the problem of over-specialization of the agglomeration could be solved by policies that stimulate mostly new technologies. Thus, the political activities should try to control the specialization of the agglomeration in the described manner. Other theoretical and empirical contributions also support this view: E.g. Krugman (1991b); Grabher (1993); Harrison and Glasmeier (1997); Porter (1998); Boschma and Lambooy (2000); Bathelt et al. (2004); Tödting and Tripl (2005); Bathelt (2005); Boschma (2005b). The corresponding measure in this context is the technological specialization of core as it was defined in Section 6.1. In relatively young industries this policy should enforce specialization and in more mature industries the focus is set on broadening the knowledge base of the agglomeration. As there is agreement about the goal, it is not easy to define concrete measures to control the specialization of an agglomeration.

The recommended policy to monitor specialization seems plausible in the chosen model, too. At the beginning each firm possesses knowledge in only one particular area of the technology space and a specialization policy would advance the amount of local external knowledge spillovers since medium values for the knowledge gaps

in technological close technologies of cluster firms favor learning. As the industry evolves, it is shown in Section 6.3 that core indicates a high level of technological specialization, which has a negative impact on the technological development of cluster firms. Policy might have two options to influence the technological specialization of the cluster: Either public institutions conduct research projects in specific technological areas, or private research is directly subsidized in order to manipulate the direction of the technological development. The first aspect is already captured in policies 1 and 2 so that we will concentrate on the direct funding of private R&D.

In the first early stages of the industry life cycle the aim is to foster specialization of core. One way to achieve this is the support of cluster firms so that they improve their most advanced technology. This is done because the cluster will establish the main technological areas in parts of the technology circle which are already at a relatively advanced level. The knowledge in those core competencies of the cluster may spill over to other firms at the core, which again guides their innovative activities to the area of interest. The creation of a technological focus in the cluster results in technological specialization. Hence, in the first periods the policy should subsidize cluster firms with R&D investments in the technology with the highest level of knowledge for process innovations.

At later stages of the industry life cycle the second part of the policy tends to enhance the diversification of the agglomeration. In the setup of the model the best option to broaden the knowledge base is to introduce new technologies in isolated areas of the technology space. Hence, as the industry evolves, the policy focuses on funding private research on product innovations. Thus, all cluster firms are supported with additional investments in the knowledge for product innovations in the technology which exhibits the greatest technological distance to its neighbors in the technology space. In this way new areas are established, which favors the market position of cluster firms and at the same time prevents a technological lock-in of the agglomeration.

The costs for the fourth type of a policy are the sum for all public subsidies to the private research of cluster firms.

Having introduced the different political measures it becomes clear that a political intervention sometimes favors several goals. In other cases the action may have negative effects on different political goals. Several political trade-offs might emerge due to the design of policies. First, a funding of non-local public research in policy 2 may reduce the incentive to agglomerate, which was defined as a goal of policy 1. On the other hand, the extension of local networks in policy 2 again favors agglomeration. Second, in policies 1 and 2 the support of public research and

networking leads to higher external knowledge spillovers, which might work against the appropriability of innovations. Third, the selective funding of firms in policy 1 and 4 may distort firm behavior, which is indeed the idea behind and reason for this type of policies. Fourth, a higher appropriability in policy 3 might work against competition policy because it might favor higher prices and market concentration. And finally, in policy 4 there is an important turning point as the policy switches from enhancing specialization to preventing a lock-in due to over-specialization of the cluster. The topic of correct timing is important and stressed by Tödting and Tripl (2005). We will assume a random time horizon for the duration of the two parts of policy 4. Thus, in general there exists a time interval without any political influence.

The four types of regional innovation policies are implemented in the model to draw conclusions concerning their impact and interaction. While designing the policies we encountered the problem of choosing the intensity that also determines the cost of the political activities. We see two possible modeling strategies: Either we analyze the outcome of different policies which are based on similar expenses, or we set the parameters in such a way that the desired result can be observed and then compare the cost and outcomes of the policies. We choose the latter option to ensure that the policy effects the relevant dimension (see Table 7.2) and that the expenses are not useless because they did not reach a critical threshold. Building on this modeling strategy we discuss the influence of the different policies on main industry characteristics afterward.

The chosen parameters values are summarized in Table A.5 in the Appendix A.2. Only changes to the standard scenario are listed. The standard setting is understood to be the reference case without political intervention. Finally, we now turn to the quantitative results of the computational experiments.

7.3.2 Simulation Results for Policies

The analysis of the simulation experiments concentrates on the four major dimension of political interventions: Number of firms in agglomeration, level of learning through knowledge spillovers, firm profits, and specialization of the agglomeration. The influence of each policy on these dimensions is investigated followed by a discussion of the costs and welfare effects. The outcome for other industry characteristics is mentioned after that. The section closes with our main conclusions and recommendations for regional innovation policy.

The first political intervention tries to enhance the incentive for agglomeration through learning from a local public institution and through direct subsidies to cluster firms. Therefore the crucial indicator of success is the number of firms at

the core which should rise due to the public influence. Figure 7.13 shows the firms which choose a location in the agglomeration for all types of policies. All graphs represent the average outcome of 100 simulation runs.

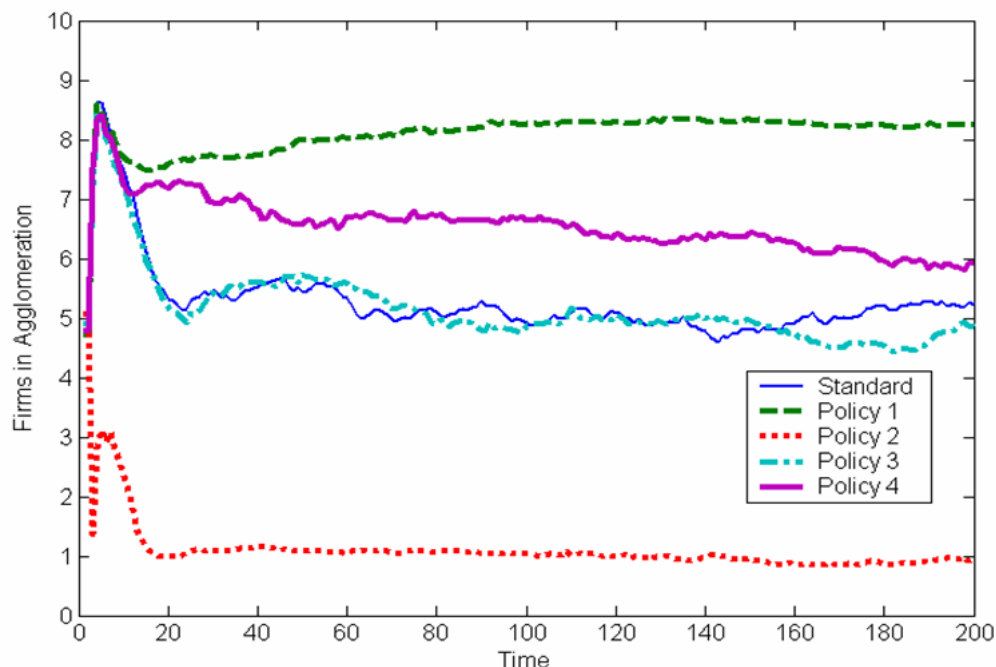


Figure 7.13: Policies and the number of firms in the agglomeration.

The thin line stands for the standard scenario and is equal to the graph in Figure 6.2 whereas all other thick lines display the changes due to the different policies. Apart from policy 3 the other policies seem to have a substantial impact on the number of firms which choose a close geographical location to their competitors. The most successful policy to enhance the incentive for core is policy 1, which can be seen from the fact that the dashed line shows the highest values and even slightly increases over time. Policy 4 also results in more firms choosing cluster although the policy mainly focuses on the specialization of the agglomeration. On the other hand, the dotted line of policy 2 indicates that on the average only one firm stays at the core. Statistical tests in Appendix A.3 support the impression of the figure.

The main finding concerning the incentive for agglomeration is the fact that policies 1 and 4 attract firms to the cluster whereas policy 2 discourages firms from agglomerating. Thus, the measures of policy 1 in the form of local public research and funding of cluster firms work in convincing firms to move from periphery to core. The tendency for core in the evaluation function for location, described by equations (4.30) respectively (A.10), are supported as firms enjoy additional local knowledge spillovers and a cost reduction in the agglomeration. Besides, the opposing effect of high knowledge leads is not that strong because many opportunities for local learning

allow all cluster firms to have a broad and pronounced knowledge base. This can for example be concluded from the fact that the average knowledge for process innovation is highest in policy 1. Since there are no firms with a particularly high knowledge lead over their competitors, more firms choose geographical proximity, which again favors local learning. This self-reinforcing process results in the very high numbers of firms at the core for policy 1. The opposite effect arises in policy 2, where firms can learn from the external institution independent of the geographical location. Therefore the potential gains from external knowledge spillovers at the core are reduced, which drives firms out of the agglomeration. This finding shows a clear goal conflict between policy 1 and policy 2 since local learning enhances and global learning reduces the incentive for agglomeration. This is in line with our intuitive suggestions at the end of the proceeding section.

In the case of policy 4 the government supports the innovative efforts of cluster firms. This effect is not directly captured in the evaluation function for location but works indirectly through an increase of local learning for all firms at the core as the public investments build up private knowledge in chosen areas. Apparently, the effect is not as high as in policy 1. The measures of policy 3 do not alter the outcome for the number of firms at the core since the increase of the consumer budget and the extension of patent length applies for all firms and should not distort the location choices of the firms.

In order to assess the adverse selection effect of clusters, which was the topic of Section 6.2, we have a closer look at the fraction between average profits of cluster firms divided by average profits of firms on the periphery. In all considered scenarios but policy 1 firms at the core are more successful at the beginning but soon after the introduction of the first new product variants the fraction falls below 1 and reaches values around 0.3 after 200 periods. Even in the case of policy 4 the minority of peripheral firms is much more profitable than the majority of firms in the agglomeration. This is not true in case of policy 1. Here the majority of cluster firms always has higher profits than the few firms in geographical isolation. The graph stabilizes at 1.2, which shows that on the average firms in the agglomeration enjoy about 20% higher profits than firms on the periphery. Hence, the only scenario without the adverse selection mechanism is policy 1. Only in this case is the incentive for core high enough even for technologically leading firms so that they prefer geographical proximity.

One of the main advantages of the simulation model is the fact that we can quantify the amount of internal and external learning within and between firms. We then turn to the second relevant dimension, which is the total amount of learning in the industry. Figure 7.14 depicts overall learning in the industry, which we understand as the sum of internal and external knowledge spillovers for process and product in-

novations and the knowledge spillovers from the (local or non-local) public research institution. All types of lines stand for the same scenarios as in the previous picture. Again the thin line represents the reference case and here the lowest amount of learning is achieved over time. Statistical tests in Appendix A.3 indicate that all policies increase learning and that the group of policy 1 and 4 lies significantly higher than the group of policy 2 and 3 at $T = 200$.

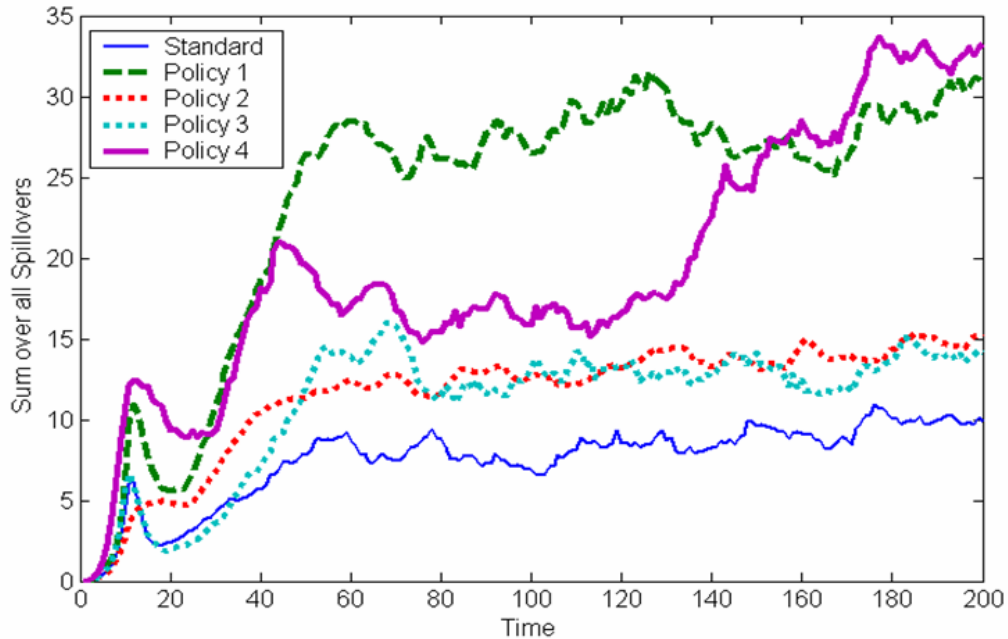


Figure 7.14: Overall learning in the policy scenarios.

In the second policy the local interaction between firms in networks is intensified, which has a positive impact on the degree of external knowledge spillovers. On the other hand, an external public institution provides knowledge for all firms in the industry. Both measures lead to an increase of learning in the industry in comparison to standard but the outcome shows that other types of policies are even more successful in enhancing learning. Apart from policy 3, which evolves similar to policy 2, the activities in policy 1 and 4 seem to generate more knowledge spillovers. In policy 1 total learning increases very fast at the beginning and then stabilizes at a high level. In policy 4 the outcome is driven by the political efforts which are mostly active at the beginning and at the end of the simulated periods. Although the evolutions in policy 1 and 4 differ, both scenarios indicate similar levels at $T = 200$.

In order to disentangle the emerging patterns for learning we discuss the different types of knowledge spillovers. As the parameters for the public research in the external institution in policy 1 and 2 are the same (see Table A.5) and in policy 1 almost all firms are located at the core, the resulting levels of knowledge spillovers from the external institution are similar, too. The internal learning within firms is

highest but the external knowledge spillovers between firms for process and product innovation are lowest in policy 2. The reason for this outcome is of course the low number of firms in the agglomeration, which is shown in Figure 7.13.

We conclude that the measures in policy 2 are not suited for enhancing total learning because a higher degree of knowledge spillovers¹⁹ and global learning opportunities lower the incentive for core and this reduces learning between firms. It seems that knowledge spillovers between firms in the agglomeration are substituted through learning from the public external institution. The amount of learning is only higher than standard because of the research in the external institution funded by the government.

It was argued that if firms economically benefit from innovation, the technological development of an industry could improve. Because of this we choose the average level of aggregated firm profits as the third key dimension and present it in Figure 7.15. The graphs and tests in Appendix A.3 give evidence that policies 1, 2 and 4 reach similar levels as standard. Although the mean and median of the other policies is slightly higher than standard, the result is not significant in the statistical test. Only policy 3 increases the average aggregated profits at a confidence interval greater than 99%.

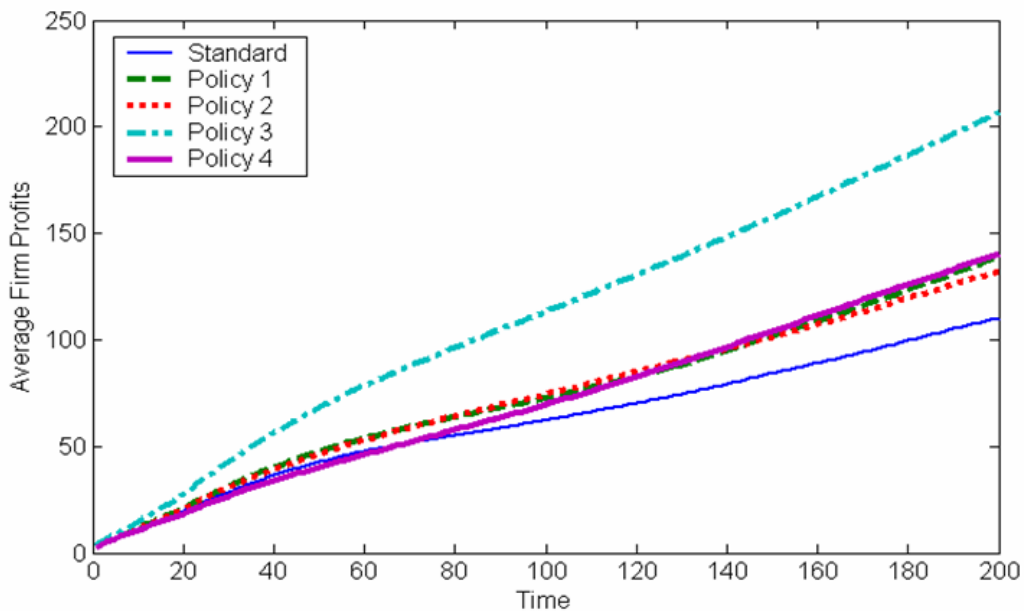


Figure 7.15: The impact of policies on the average aggregated firm profits.

The extension of the patent length and the direct support for consumers in policy 3 make the firms on the average more profitable. The total consumer budget for the

¹⁹See also Figure 6.5 which indicates that a higher degree of knowledge spillovers lowers the incentive for agglomeration.

industry is also highest in this scenario. In all other scenarios the evolution of the consumer budget is lower than in policy 3 but evolves similarly. After $t = 100$ the support for product innovations in policy 4 leads to more radical product innovations, which raises the total budget of the industry.

The consequences of policy 3 are quite straightforward: Firms economically benefit from the higher consumer budget, and the appropriability of product innovations is extended. The consumers still prefer the same type of products but now they can either buy a higher quantity or pay a higher price. Indeed the prices in the policy 3 scenario are highest over all periods. As the production costs stay constant, even the technologically lagging firms earn higher profits. This can be seen from the fact that policy 3 has the lowest number of bankrupt firms and the lowest level of industry concentration in profits. The question whether higher profits due to political activity do indeed enhance the technological development of the industry is not obvious. On the one hand, there is a clear positive influence on the number of successful product innovations as policy 3 has the most new products until it is later on overtaken by policy 4. On the other hand, the best-practice and average level of knowledge for process innovations is still higher than standard but lower than the other policies. Of course the higher number of technologies makes it harder to keep a high level of knowledge in each of those technologies. We will come back to this point in the context of policies and technological development.

The last dimension for the analysis of policy is specialization of the agglomeration. As shown in Section 6.1 the interpretation of specialization captures two aspects, namely specialization in height and specialization in location. The specialization of an agglomeration is based on the knowledge of all firms that are at that time located in the cluster. As discussed above, from a policy perspective it would be beneficial to enforce specialization in early times and diversification later on. This is done because diversification prevents a lock-in of mature industries. The evolution of specialization of the agglomeration, measured as the mean over specialization in height and location of all cluster firms, is introduced in Figure 7.16. The standard scenario together with policy 3 take a middle position between very high specialization in policy 2 and lower values for policy 4 and policy 1. There is also statistical evidence for this ranking in Appendix A.3. The patterns for each individual form of specialization qualitatively show the same result.

As a first finding we admit that in the first half of the simulations policy 4 does not succeed in generating a more specialized agglomeration than standard. The subsidies to help cluster firms extend their core competencies even lead to a more diversified agglomeration, which can be seen in the low values of the specialization indicator. At later times, around period $T = 100$ when policy influence is lowest, the cluster gets more specialized but does not reach the level of the reference case. If we

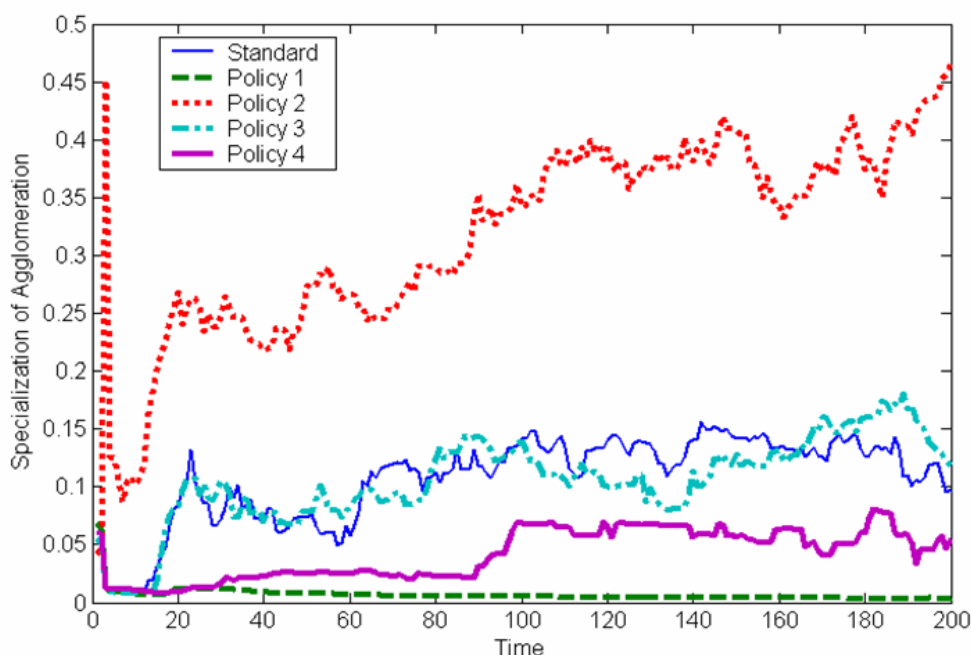


Figure 7.16: Policies and specialization of the agglomeration over time.

look at the specialization of the whole industry, we discover a major change in the case of policy 4. After an initial phase the specialization in policy 4 increases fast and reaches a peak around $T = 50$ when the specialization policy starts to slow down. In this peak the specialization of the industry in policy 4 is approximately twice as high as in standard. In all other scenarios the specialization of the industry evolves similar. Therefore, the early policy 4 does not succeed in generating specialization of the agglomeration but it does foster the specialization of the whole industry.

Two reasons for the diversified agglomeration in early periods can be given despite the specialization efforts of the policy: Learning and the design of the measure itself. The focus of policy 4 concentrates on the highest knowledge peaks of cluster firms and changes if the highest possible level is reached. Thus, in this scenario the best-practice develops very fast with the help of policy. Firms in the cluster get support in several technologies, which works against specialization. The other mechanism is learning through knowledge spillovers in the agglomeration as most of the firms choose close geographical proximity. Through the public activity the amount of knowledge spillovers rises but learning in several technological areas again favors diversification. Indeed firms in policy 4 are on the average less specialized in comparison to the other scenarios. This is particularly true for the first half of the simulated time horizon. Hence, mostly the learning opportunities in combination with a high incentive to agglomerate counter-effect the political goal and lead to diversified firms and a diversified agglomeration.

In the second half of the simulations policy 4 switches to fostering diversification of the agglomeration. We can see in Figure 7.16 that the efforts succeed as the degree of specialization of core stays constant or even decreases over time. When we compare the first and the last political goal, we detect that the ranking in the number of firms at the core over time is the opposite of the outcome for specialization of core. For example policy 2 (1) has highest (lowest) specialization with lowest (highest) average number of cluster firms. The cause is learning through knowledge spillovers in combination with the mechanisms described in the previous paragraph. Hence, there appears not only to be a negative correlation but also a causal relationship between the number of cluster firms and the specialization of the agglomeration. The more firms agglomerate, the lower is the propensity for high specialization and thus for a lock-in situation of the agglomeration. A policy that enhances the incentive to cluster at the same time works against an over-specialization of the agglomeration.

So far we have debated the effects and the interdependencies of the different policies. Not only the consequences but also the costs for implementing the policies differ. Building on the measurement introduced before we present the evolution of the current policy costs in Figure 7.17. The amount of money which is spent in each period increases for policies 1 to 3 and is mostly constant with a slowdown in middle periods in the case of policy 4. In later times the implementation of policy 1 is the most expensive one, followed by policies 3, 2 and 4. In the reference scenario no policy costs occur. The picture shows current costs in every period and additionally we investigate the sum of policy costs over all periods with the help of statistical tests in Appendix A.3. The analysis suggests that the above ranking holds for the total cost and is highly significant, too.

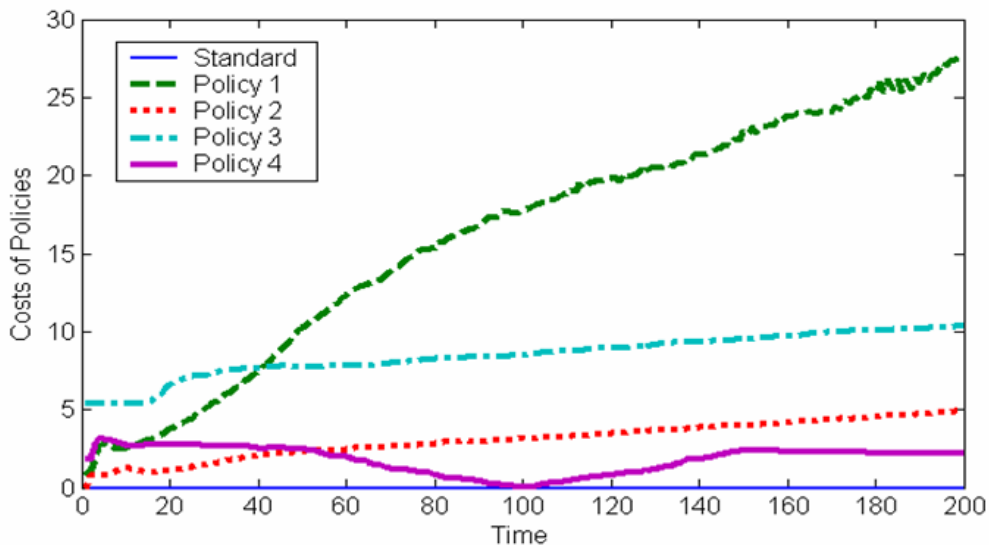


Figure 7.17: The current costs of each policy over time.

The costs for most of the policies rise because the complexity of the technology space increases over time, which results in higher costs for the external institution in policies 1 and 2. The same holds for policy 3 as more radical product innovations extend the financial support of the consumer budget. Additionally, the costs for policy 1 rise with the quantity produced in the agglomeration. The direct support of cluster firms in policy 4 is rather constant since the number of firms at the core does not fluctuate much in this scenario. By assumption the point in time where the policy switches from specialization to diversification is set randomly. On the average this leads to lower expenses of policy 4 between $t = 50$ and $t = 150$ and reaches its minimum at $t = 100$, see also Table A.5. To get an idea of the height of the political costs we calculate them in percentage of the consumer budget. We find that at the end of the simulations on the average the expenses for policy 1 are approximately 54%, for policy 3 around 16%²⁰, for policy 2 around 10%, and finally for policy 4 around 4% of the consumer budget. In the case of policy 1 this means that the government has expenses which are more than half of the amount all consumers spend on products of this industry. Because of this, it appears to be very difficult to justify political interventions in the form of policy 1. For regional innovation policy the other policies rather seem to be affordable.

The last industry characteristic we look at is the welfare of the industry. Welfare, as defined in Section 4.2, is a global indicator which aggregates information about technology space, prices as well as firm profits and it stands for the sum of the benefits of firms and consumers. However, the costs of political interventions are not included. Figure 7.18 presents the evolution of welfare in the different scenarios. The outcome at $T = 200$ shows that policy 3 performs significantly better than policy 4 and that policy 4 achieves higher values than policy 1 which is again better than standard. These results can be obtained to a confidence interval greater than 90%. The statistical test in Appendix A.3 suggests no significant difference between policy 2 and standard. The high values in the first period emerge due to the chosen initial conditions and are not relevant.²¹

According to our observations welfare increases in all considered scenarios over time. In particular the values escalate after the first new products around $t = 20$. Over the whole time horizon the highest welfare is reached in policy 3 and the bottom line is represented by standard. Hence, all policies advance the mean values of welfare though the increase at $T = 200$ is not significant in the case of policy 2. The development of the curves stays qualitatively the same if we consider the

²⁰The theoretical expected value from the randomly generated parameter change due to policy 3 is $0.5 \cdot (4 - 3)/3 = 0.1667$.

²¹By assumption all firms in the first period simultaneously choose x_{min} as output quantity, see Section 4.3.2. After that, the quantity decision is based on more sophisticated decision rules which incorporate the strategic effects on competitors and consumers.

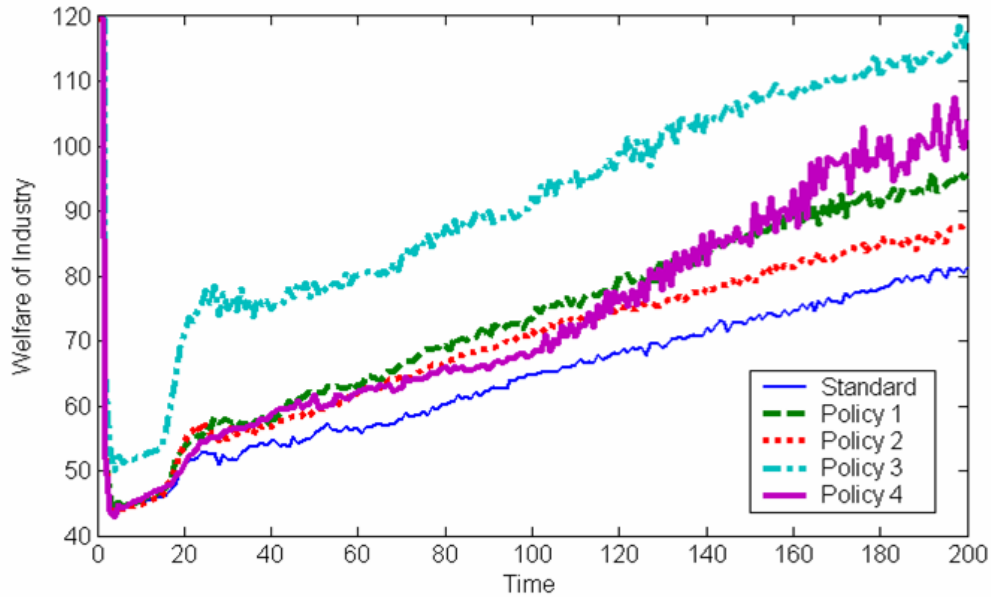


Figure 7.18: Policies and the evolution of welfare of the industry.

evolution of consumer or producer surplus separately.

The only major change in the ranking of welfare over time occurs in policy 4. Here the policy manages to develop welfare from the last position before period $t = 100$ to the second best position at $T = 200$. During this time the policy concentrates on diversification of the agglomeration through subsidizing product innovations of cluster firms. This form of policy appears to have a very positive influence on welfare. The result is driven by the fact that radical product innovations especially increase the welfare of the industry. As shown in the picture the measures of policy 3, which extend the patent length and support consumers' budget, generate the highest level of welfare. The politically induced higher appropriability of the industry favors both - innovating firms and consumers. The firms enjoy higher economic profits and this again supports the private innovation efforts. The consumers in policy 3 can spend more money and are free in their choice of product variants. Despite the higher prices in that scenario the consumers benefit most from this policy. The same is true for the firms as they exhibit the highest level of producer surplus.

In short we now introduce important results of other main industry characteristics without visual presentation. We start with the technological development of the industry which incorporates product and process innovations. Policy 3 exhibits the most radical and incremental product innovations until it is overtaken by policy 4. The major increases in the number of new product variants in policy 4 happen in consequence of the diversification policy in the second half of the simulations. Policy

1 manages to generate more product innovations than standard, but the outcome in policy 2 is very close to the reference case. The ranking for the development of the best-practice for process innovations is the following: Policy 4 performs best, followed by equal values for policy 1 and 2. The slowest increase of the highest knowledge peak can be observed in policy 3. This pattern is driven by the political interventions which either support the best-practice, e.g. in policy 4 in early periods, or set the technological frontier due to the external institution in policies 1 and 2. The funding of the external institution also leads to very good results for the average level of process innovation in policies 1 and 2. The average process innovations in policy 3 evolve just close to, but above standard. At the beginning the mean process innovations in policy 4 are better than in the other policy scenarios but later on the high number of product innovations lowers the average level. At the end of the simulations the values even fall below standard.

We also have a look at prices, market and industry concentration. The development of prices indicates that on the average prices are higher in the case of policy 3 and slightly lower in policy 4 than in the other policies which lie close to standard. In the long run the prices converge to the same level in all scenarios. From the relatively high prices in policy 3 one would expect high market concentration but this is only the case during the periods following the wave of new products at $t = 20$. Despite the high number of product variants in policy 3, after that the markets are less concentrated than in policy 4. In a mature industry the market concentration even falls below the value of policy 1. Hence, the markets are dominated by fewer firms in these scenarios. As market concentration shows the differences of output quantities on a market, the industry concentration gives an idea of the distribution of aggregated profits across all firms of the industry. A high level of industry concentration would indicate that few firms earn much more profits than the majority. In fact, at the end of the simulated time the highest industry concentration can be observed in standard, followed by a group consisting of policies 1, 4 and 2, and policy 3 has the lowest industry concentration.

This is an important finding because it shows that an industry which is left on its own generates higher differences between firm profits than any scenario with political influence. In an industry without political interventions the more competitive firms benefit more relative to the less competitive firms. The profits of the highly competitive firms might for example be higher in policy 3, but the difference compared to the weaker competitors is relatively lower. In other words, the political measures mainly help less competitive firms not to fall behind and, at least in terms of profits, to keep track with the technological leaders. The separation between successful and not successful firms is strongest if the competition is not distorted by any policy. This is a nice exemplification of the possible negative influence of public authorities

on competition mentioned by Porter (1998).

In the following we summarize the main points and propose a normative judgment in terms of a cost-benefit analysis for every policy. We start with policy 1. Here the goal is to enhance the incentive for core as the local positive externalities increase with the number of firms in the agglomeration. The policy indeed makes it possible to increase the number of firms taking part in the local learning with the help of direct subsidies and public research in the cluster. The total amount for learning is highest compared to the other cases and most of the knowledge spillovers happen between firms and not from the external institution to firms. The policy influence is that pronounced that not only the technologically lagging firms but also the most profitable firms choose geographical proximity. Hence, this is the only scenario where the adverse selection effect of clusters does not emerge. As the overwhelming majority of firms locate in the cluster, the technology base of core is very diversified and no technological lock-in occurs. Especially, the support of local research facilities favors the development of the best-practice and the intense learning in the agglomeration leads to a fast diffusion of knowledge and a high average knowledge. With the number of established new products, which has a strong impact on welfare, policy 1 takes a middle position. The high market and industry concentration indicate that the industry is selective in the sense that more competitive firms perform better relative to less competitive firms. The many positive features of this kind of policy intervention come with very high implementation costs. In particular the direct support for cluster firms boosts policy costs. Therefore, we conclude that policy costs - higher than half of the whole consumers' budget for this industry - are too high to justify this policy despite the positive effect on attracting technologically advanced firms to the cluster. One possible solution could be to concentrate on the support of local research, which alone seems affordable. The local research institution is also alone responsible for many of the positive consequences in connection with policy 1.

The funding of a public research institution is much less expensive than the overall costs in the previous policy, which can be seen from the analysis of costs for policy 2. Apart from the public institution which provides cluster and peripheral firms with knowledge, this policy also captures costs for the intensified learning between firms in the agglomeration. The main problem of this policy is that it conflicts with the goal of previous policy 1: The public non-local institution as well as the higher degree of knowledge spillovers drive firms out of the agglomeration and this almost annihilates external knowledge spillovers. Therefore, policy 2 is only responsible for a small increase in total knowledge flows because learning between firms is mostly substituted through learning from external institution. Further, the low number of cluster firms results in a fatal lock-in of the cluster. The low level

of learning mainly has an impact on product innovations whereas the best-practice and average process innovations develop satisfactorily. This happens because of the external institution and the fact that the technology space consists of only a few technologies. Another major argument against this policy is given due to the low welfare effects since policy 2 cannot generate a significantly higher welfare than standard. Hence, despite the reasonable costs we do not recommend measures like policy 2 because they do not succeed in reaching the aim of a substantial increase of knowledge transfers and welfare.

The aim of policy 3 is to increase appropriability with an extension of patent length and a financial support for all consumers. Indeed, the policy succeeds in generating additional firm profits. The technological development of the industry shows that in the first two thirds of the simulation this scenario has the most new incremental and radical product innovations. The high number of technologies makes it hard for firms to keep a high average level of knowledge but here the outcome for best-practice and average knowledge is still higher than in standard. High firm profits and many radical product innovations result in the highest welfare level of all considered scenarios. The welfare at the end is about 50% higher than in standard. On the other hand, the relatively high policy costs and the lowest industry concentration can be seen as potential drawbacks of policy 3. The profits of the firms are relatively more equal and very high compared to the other scenarios. The less competitive firms benefit more than competitive firms because longer patents hinder firms from penetrating new markets and an entry of firms in this industry is not possible by assumption. In conclusion, despite the high costs we recommend policy 3 because of the welfare analysis, the positive technological outcome, and the fact that not the government but the consumers guide the direction of the technological development with their increased budget. At the same time we have to keep in mind that the politically induced entry-barriers may conflict with competition policy.

In the case of policy 4 it is argued that in the early phases of an agglomeration policy should try to enforce specialization and later diversification of the cluster. We implement these efforts by subsidies to initially process innovations and later product innovations. The outcome shows that it is not possible to enhance specialization because the support links firms to core, which favors local learning, and the high amount of external knowledge spillovers prevents specialization of the agglomeration. Later on the policy is more successful in the diversification activities. The high number of cluster firms in conjunction with learning favor the goals of policies 1 and 2. The financial support for product innovations advances the number of incremental and radical innovations. This has a positive influence on the development of the welfare. Although the specialization policy assists the evolution of the best-practice, the numerous product innovations in the second half of the time horizon let the

average level of knowledge for process innovation fall below the reference scenario. One possible drawback of the policy is the high market concentration due to both forms of political influence: Specialization activities help cluster firms to extend a technological lead and prevent entry, whereas diversification policy favors product innovations which are associated with a temporary monopoly, too. Taking the low implementation costs into account we think that the positive effects outweigh the negative and we thus recommend policies of that type. The diversification strategy even seems to be more favorable than policy-induced specialization.

As the main findings of this section we conclude that policy can influence the form of competition and the technological development of an industry but the outcome and costs of policies are very different. All discussed policies lead to more learning and, thus, more innovations but in general firms with lower technological capabilities are subsidized. Like in the previous Section 7.2 there appears to exist a trade-off between static and dynamic efficiency because a better technological development of the industry is often connected with monopolistic tendencies. Although the costs for an external institution rise with the complexity of the technology space, a local external institution attracts firms to the agglomeration and might prevent a technological lock-in. A policy focusing purely on non-local learning does not result in substantially higher knowledge transfers because firms substitute private through public learning. The same is true for an intensification of the learning processes between firms in close geographical proximity. More knowledge spillovers do not enhance the incentive for agglomeration, see Section 6.2. An advisable policy is to improve appropriability with longer patents and subsidized consumer budgets as the welfare increases most with this measure. Applied local public research should focus on new technological areas instead of improving existing technologies in order to diversify the technological spectrum of the agglomeration.

Building on the results we will try to provide advice for a regional innovation policy, despite the fact that the model only considers a very special case of a horizontally related agglomeration. The analysis shows that financial support to firms has to be relatively high in order to attract firms to the agglomeration. Thus, policy should concentrate their efforts on the support of research either in cooperation with firms in the form of innovation projects or in public research institutions. Further, it is of high importance that public research is provided on a regional level and that companies are motivated to start exchanging knowledge in geographical proximity. The policy may create a local forum in which firms and public research can interact and firms can meet each other. Public research activities should rather aim at broadening the technology space than at deepening existing technologies. Furthermore, we think that policy should support consumers rather than firms because consumers know best which product variant they are willing to purchase and

thereby guide technological progress. The establishing and protection of intellectual property rights is useful to increase the appropriability of innovations. The theoretical analysis also indicates that policy measures might distort competition and that less competitive firms benefit more than technologically advanced firms. This might work against one of the greatest advantages of the market, namely the selection mechanism.

7.4 Summary

The topic of this chapter is the analysis of the simulation model from a policy perspective. The focus is set on the influence of geographical and technological proximity on the innovation outcome and welfare analysis. We give an idea of how location distributions of firms, industry conditions, and policy interventions change the quantitative results of the model.

In Section 7.1 we find that the technological development in standard is better for firms on the periphery. This explains the result in Chapter 6, where firms on the periphery are much more profitable than firms in the agglomeration. We continue with the analysis of settings which differ in their fixed number of firms at the core. We discover that more radical product innovations occur in the 0% core scenario and more incremental product innovations happen in 100% core. This result also holds in the case of process innovations and emerges due to the difference between internal and external learning. Further, the model suggests that the more firms are located in the agglomeration, the lower are profits in the scenarios with no possible change of geographical proximity. The welfare indicator, as defined in Section 4.2, would prefer 0% core mostly because of the higher number of radical new product variants and higher firm profits. Moreover, welfare is lowest in the scenario with standard parameter choice.

Section 7.2 debates the consequences of a technological environment or regime on innovations. Here several parameters of the model are altered to represent two archetypes of technological regimes: Schumpeter Mark I and Schumpeter Mark II. The two scenarios differ in the opportunity, cumulativeness, and appropriability conditions as well as the knowledge base of the industry. Concerning the technological development we find more radical product innovations in Schumpeter Mark I but more incremental product innovations, higher best-practice and a faster diffusion of knowledge for process innovations in Schumpeter Mark II. The latter outcome comes with higher market concentration and lower industry concentration. These findings indicate that there is no ideal technological regime because both types have their own merits which contribute to different political goals. One can speak of a potential trade-off between dynamic efficiency in terms of a more innovative and static effi-

ciency in terms of a more competitive industry. Furthermore, firms in Schumpeter Mark II appear to be less specialized in their technological portfolio, which is caused by the type of learning through knowledge spillovers and by the effect of 'creative destruction'. This part of the book is also interesting from a methodological point of view since it proves that theoretical results from simulation models can be replicated and testified by a third person. Here, this is done with the simulation model by Winter (1984) and most qualitative findings are reproduced with our model. Apart from the comparison between the two models we propose new arguments to the debate about technological regimes.

Section 7.3 reveals a normative character in the discussion of regional innovation policies. We start by providing a rationale for political activities in the setting of our model. Equilibrium and evolutionary analysis in the literature as well as the arguments of Section 7.1 seem to justify political interventions. Four policy options and their potential costs are highlighted: Enhance incentives for agglomeration, foster learning through knowledge flows, increase appropriability, and control specialization of agglomeration. The first policy advances the number of firms at the core sharply, which also favors local learning. Firms and the agglomeration indicate a very diversified knowledge base and the industry is almost as selective as the standard scenario. The main drawback of the first policy are the very high implementation costs. The second policy option is less costly but the measures discourage firms from agglomerating, which almost offsets all external knowledge spillovers. Furthermore, no significant welfare improvements occur. This is not the case with the third policy. Here, the welfare attains the highest level which is however combined with high policy costs. The activities focusing on appropriability increase firm profits, which has a positive influence on product innovations. Although the many new product variants lower the average knowledge for process innovations, it could be advisable to implement this form of policy. Both measures of the fourth policy lead to a technologically diversified agglomeration. An increase in the number of cluster firms, good results for innovations and low implementation costs are arguments in favor of this policy option. The only point against it are monopolistic tendencies indicated by high levels of market concentration. The section closes with concrete advice for a regional innovation policy.

At this point the chapters with new findings for innovation and proximity end. The simulation experiments build upon the description of the model which again rests on the theoretical debate in the literature proposed in the previous chapters. We will now turn to the last chapter with an overview and conclusions of the book.

Part IV

Lessons Learned

Chapter 8

Conclusions

This book treats the influence of different interpretations of proximity on innovative competition between firms. We concentrate on geographical and technological proximity and investigate their impact on learning through knowledge spillovers and the technological outcome in the form of product and process innovations. A deeper understanding of innovation and proximity helps managers to develop and extend their own capabilities, which determine the economic prosperity of the firm in the long run, and politicians to create and implement adequate policy measures to strengthen the competitiveness of a region or country and foster economic growth. Therefore, our research tries to disentangle relevant mechanisms using a computational tool for the experimental study of a dynamic industry.

Although many scholars have proposed economic models which deal with innovation and proximity, we opt for a new formulation in the form of an agent-based simulation model. We prefer this methodology because we can implement at the same time innovation dynamics, endogenous location decisions, complex learning functions, and a changing technology space which is also related to the preferences of consumers. We argue that these features are necessary and enable an examination of various fields. Further, we see the process of verification and validation as an elementary part of the model. We perform a sensitivity analysis to indicate crucial parameters and compare model outcome with empirical regularities.

The application of the model to selected issues constitutes the largest part of the book. In the following we want to highlight the main findings of our approach and answer the research questions raised in the introductory Chapter 1. While doing so we bear in mind that our answers are not universally valid but limited in several ways which we discuss afterward.

Answers to Research Questions:

1. Should firms seek for geographical proximity to competitors? Do positive effects of external learning outweigh negative effects due to the loss of knowledge lead?

The answers to these questions can be found in Sections 6.2 and 6.3. During our experiments we have developed a very pessimistic perspective on the benefits of local learning between competitors. The main causes for this insight can be seen in the adverse selection effect in agglomerations (see question 3) and the coordinating role of knowledge spillovers. Both mechanisms work against local benefits as the potential of external learning decreases and the firms in the agglomeration become technologically similar, which erodes firm profits. The fact that higher knowledge spillovers even lower the number of firms in the cluster also supports this insight. Firms should choose geographical proximity if firms located in the agglomeration exhibit advanced knowledge in several areas of the technology space. However, our results suggest that in general this is not the case. For an economically successful firm there is not much to gain but a lot to lose from knowledge spillovers in geographical proximity to competitors.

2. Does the importance of geographical proximity change during time?

Section 6.2 deals with the evolution of the incentive to agglomerate. Our experiments have shown that the importance of geographical proximity is not stable but decreasing over time. In our opinion the main cause for this effect is the rising significance of internal as opposed to external knowledge spillovers. As the industry evolves, the amount of knowledge spillovers within firms increases and even overtakes the sum of knowledge spillovers between firms in the agglomeration. Over time firms concentrate on their own research activities, and external learning in most cases does not strengthen their own core competencies. This self-reinforcing effect again lowers the attractiveness of the agglomeration but cluster firms are tied to the agglomeration due to a lock-in mechanism, see Section 6.3. Firms leaving the agglomeration still have to compete in the same areas of the technology space and now they lose the benefits of local knowledge spillovers - even if these effects are very limited. In conclusion we find a strong incentive for geographical proximity in young industries but the potential gains from local learning, and therefore the significance of geographical proximity, decrease over time.

3. What kind of firms enter agglomerations: Technologically advanced or technologically weak firms?

Our simulation experiments indicate that, in general, technologically weak firms seek the exchange of knowledge through local learning, see Section 7.1. The number of product innovations, the development of best-practice as well as the average level of process innovations show clearly that firms in the agglomeration are technologically behind those in peripheral locations. Even more distinctive is the evolution of firm profitability, see Section 6.2. The simulation outcome demonstrates that profits of cluster firms stagnate or decline whereas profits of firms in geographical isolation are much higher and even increase over time. Hence, we observe a clear adverse selection effect which attracts mostly technologically weak and less profitable firms to the agglomeration. Although this effect is quite surprising for the theoretical contributions to innovation and proximity, we note that several empirical studies support our result.

4. Are firms that specialize in their innovation efforts more economically successful than firms that diversify?

This topic is covered in Sections 6.1 and 6.3. The regression analysis shows that in the standard scenario those firms earn higher profits which are more willing to enter new markets, stay longer in already served markets, or attach a higher weight to market potential than to proximity to their own technological focus in the market entry and product innovation decision. Thus, in this setting more diversified innovation efforts appear to be more profitable. In the investigation of industries with different firm strategies the scenario where all firms follow a knowledge-oriented (or specialization) strategy performs best, followed by random behavior and standard parameter values. Here a profit-oriented (or diversification) strategy evolves similar to standard and has significantly lower levels of aggregated profits than the outcome for knowledge-oriented strategies. Therefore, if all firms target attractive market niches and neglect their own technological strengths, the overall profits are lowest. This supports the view of technological core competencies and, hence, specialization of firms. In conjunction with the first result we recommend that firms should concentrate on their own technological focus aiming at specialization, but a single firm might benefit from diversification efforts in attractive areas if all other competitors follow balanced or specialization strategies. Furthermore, we emphasize that knowledge spillovers - just as coordinated firm behavior - lead to technological similarities, which diminishes firm profits due to increased competition.

5. What kind of agglomerations emerge: Technologically specialized or diversified agglomerations?

Section 6.3 is concerned with the technological specialization of the two possible locations. We detect that agglomeration becomes specialized over time, which means that the technology space indicates a clustering of few accentuated peaks whereas the technology space of the remaining firms displays a higher number of peaks which are more equal in height and evenly distributed. The adverse selection effect in combination with knowledge spillovers leads to this result where cluster firms only manage to achieve pronounced knowledge in some technologies and compete mostly in the same markets. As highlighted in Section 7.3, overspecialization is often a problem in old industrial regions. This situation also emerges in the simulation model and constitutes a technological lock-in because firms in the agglomeration are not able to extend to and to absorb knowledge from other parts of the technology space.

6. What technological environment supports the flow of knowledge spillovers?

The discussion of the technological environment is addressed in Sections 6.3 and 7.2. In the literature numerous articles debate the questions whether a specialized or a diversified surrounding favors knowledge spillovers. We do not agree with this simplistic view on the appearance of knowledge spillovers. Instead we put forward the argument that the main characteristics of technological regimes determine both - the height of knowledge spillovers and the degree of technological specializations. Indeed we observe differences not only in height but also in structure of the knowledge flows in the selected two archetypes of an innovative industry. Furthermore, knowledge spillovers might even shape the technological environment (not vice versa) because they enhance specialization.

7. Can political interventions aiming to foster the technological development be justified?

Section 7.1 provides a comparison of scenarios which differ in their number of firms located in the agglomeration. The simulation experiments suggest that the standard scenario is inferior to other scenarios in terms of welfare, product, and process innovations. For example the situation without learning between competitors leads to a higher best-practice and more radical product innovations which at the same time has a positive impact on our welfare indicator. On the other hand, the diffusion of knowledge happens faster the more firms participate in the learning process. There appears to exist a trade-off between higher best-practice without and higher average knowledge with ex-

ternal knowledge spillovers. Although there is no setting which dominates all others in every considered indicator, we believe that the existence of scenarios with higher welfare than a left-alone industry justifies political interventions.

8. What are possible measures of regional innovation policy in this context and do they work?

In our review of regional innovation policy in Section 7.3 we work out four policies which might be useful: Enhance incentive for agglomeration, foster learning through knowledge flows, increase appropriability, and control specialization of agglomeration. We implement these policies to evaluate their effectiveness. While doing so we discover large differences in the cost of policies. Further, interventions in favor of one political goal sometimes conflict with another, e.g. the possibility of global learning for all firms independent of their location drives firms out of the agglomeration. Innovation policy may also conflict with competition policy as the measures mostly help firms with lower technological capabilities and a better technological development is often connected to monopolistic tendencies. Regarding the cost-benefit analysis we recommend a support of appropriability conditions and local learning mechanisms aiming at the diversification of the local knowledge pool.

The proposed answers to the research questions are of course not exhaustive, rather they present our arguments to the ongoing theoretical debate on those important issues. Our arguments rest on our view and understanding of the economy, which again determines the formulation of the agent-based simulation model. Like all (simulation) models this model is limited due to the chosen functional form and setting of parameters. For example another interpretation of the demand side, firm strategies or learning processes would probably alter the results. Although we give attention to the specification of the parameters (and many of them are not as influential as the functional form), our findings rest on a limited parameter range as it is not possible to consider the full parameter space.

During discussions with other scholars our approach was criticized in the way that simulation models are too generic and should always try to calibrate critical parameters to match quantitative and empirically obtained parameters from specific industries. We argue that one can also use simulation models to formulate sophisticated behavior of agents in a complex environment in order to identify more general mechanisms which could not be studied with conventional methods. Like in the case of all theoretical insights the propositions we derived have to be confronted with reality to prove their validity. The outcome of the simulation model is compared to

empirical studies but here we do not take into account differences between industries. Another approach could be seen in the calibration of the model according to specific industry characteristics and then try to reproduce stylized facts of a certain industry. The calibration of the model to a certain industry would lead to new insights about the process of innovations in different industries. We - at least in a first step - prefer to investigate more qualitative effects which might hold for several (or even all) industries. The industry specific analysis of the model is possible and will be left for future work.

Although we speak about learning all the time, firms in our model are not able to adjust their decision rules. The lack of learning in the form of adaptive firm strategies may be seen as a major disadvantage of the model. On the other hand, the rigid behavior of the agents is also a merit because it exaggerates certain aspects which otherwise would not emerge that clearly or simply would not have been recognized. For example adaptive routines might lead to smaller differences in profits between cluster firms and firms on the periphery. The aim of this work is not to build the most realistic model but to disclose relevant functions driving the results. In this case overstatement may help to stress certain mechanisms. Hence, in order to identify elementary effects we restrict our experiments to constant routines. Nevertheless, to go further we need to test our outcome with adaptive decision rules and discuss whether some of the mechanisms mentioned become less evident or not.

Furthermore, this model concentrates on knowledge spillovers between direct competitors as the only agglomeration and de-agglomeration forces.¹ Of course one can introduce other advantages and disadvantages of agglomerations into the model such as knowledge flows to and from suppliers or customers, benefits from specialized inputs or labor market pooling. Another drawback of the model can be seen in the fixed number of firms in the industry. The modeling of industry entry and exit as well as new firm formation, e.g. through spinoffs, are other possible extensions worth trying. Further, we can think of separating the technology from the product space and introduce more independent consumer agents which also might adapt their preferences during a simulation. In the current form the model only incorporates the interaction on a product market. Thus, adding labor, credit or capital markets enables the discussion of a wide scope of fascinating research questions.

As a last possible extension to the model we think of a more complex geographical landscape, for example several agglomerations or a cellular automata framework. Especially, a model consisting of several regions or countries allows a debate on the topic of convergence and cohesion. If we assume the existence of local positive externalities, every government has to decide whether it should differentiate between advanced or lagging regions. The question of regional equality and economic effi-

¹In some scenarios congestion costs are also considered, see e.g. Section 6.2.

ciency becomes crucial and economic policy has to decide whether it should avoid, tolerate, or even foster regional concentration of economic activity. This is relevant for single countries like Germany and at the same time for institutions like the European Union. Following this argument the general goals of the Lisbon strategy mentioned in the introduction are liable to criticism. For example Werker (2006) argues that it is not possible to stimulate growth and achieve cohesion at the same time because positive cumulative and self-reinforcing processes go hand in hand with an agglomeration of economic activities.² This topic definitely begs for more research and more interactions between scientists and policy makers.

We are convinced that the methodology of agent-based simulation is able to contribute to these issues. There still remain several questions to be dealt with and further examination on the topic of innovation and proximity will yield many fruitful results which are of great importance for academia as well as for firm managers and politicians.

²See also Martin (1998) and Martin (1999a) on this point.

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Appendix A

Appendix

A.1 Consumer Surplus

In order to perform a welfare analysis, we develop a consumer surplus function. The consumer surplus for every sub-market j depends on the range of attracted consumers indicated by $\bar{a}_{j,t}$ and $\bar{b}_{j,t}$ in equation (4.14), the actual price $p_{j,t}$ and a consumer specific maximum price $p_{j,t}^{max}(a)$. This last value indicates the maximum price a consumer located in a would pay on sub-market j . If the price $p_{j,t}$, on this sub-market exceeds this level, the consumer in a would buy a product variant from the next neighboring relevant markets $j-$ or $j+$. Which sub-market the consumer will choose depends on the prices, the technological distances between the markets and of course on the technological location of the consumer.

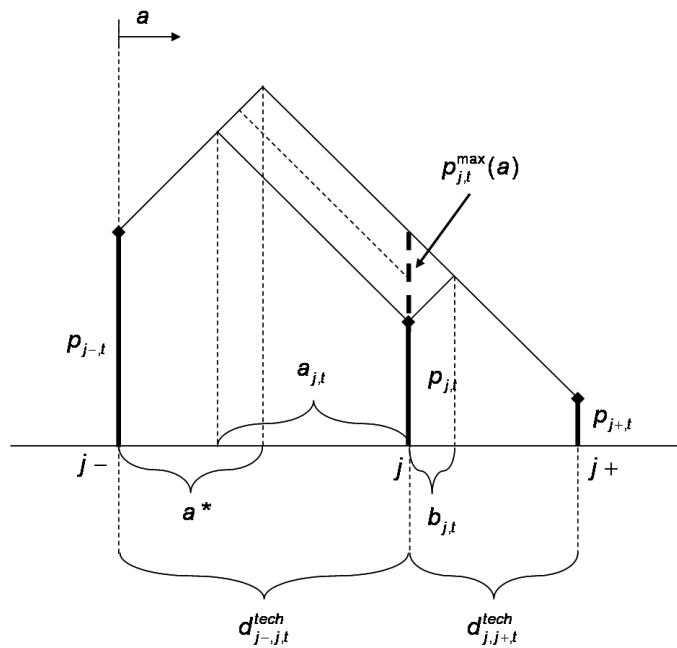


Figure A.1: Calculation of the maximum price $p_{j,t}^{max}(a)$ for a consumer located in a .

The situation is sketched in Figure A.1. In this situation the consumer evaluates according to equation (4.12) the three alternative product variants $j-$, j and $j+$ as well as the corresponding technological distances. As long as the price $p_{j,t}$ is smaller or equal $p_{j,t}^{max}(a)$ the consumer will demand on market j . The possible range of values is indicated in the figure with a thick dashed line.

In order to differentiate several cases we first compute the value a^* which stands for the indifferent consumer between the markets $j-$ and $j+$ neglecting sub-market j :

$$\begin{aligned} p_{j-,t} + a^* &= p_{j+,t} + d_{j-,j,t}^{tech} + d_{j,j+,t}^{tech} - a^* \\ \Rightarrow a^* &= 1/2 \cdot (p_{j+,t} - p_{j-,t} + d_{j-,j,t}^{tech} + d_{j,j+,t}^{tech}) \end{aligned} \quad (\text{A.1})$$

Because $j-$ and $j+$ are the relevant neighbors of market j the value for a^* has to lie in the interval $[d_{j-,j,t}^{tech} - a_{j,t}, d_{j-,j,t}^{tech} + b_{j,t}]$. Here two cases appear which lead to different functions for the maximum price. First, it could be a situation like the one in Figure A.1 where a^* lies left to market j , or $a^* \leq d_{j-,j,t}^{tech}$. Second, a^* lies right to market j , or $a^* > d_{j-,j,t}^{tech}$. In each of the cases three different parts are defined, which give the maximum price $p_{j,t}^{max}(a)$ a consumer in a is willing to pay at market j .

In the first case for $a^* \leq d_{j-,j,t}^{tech}$, which corresponds to the figure, $p_{j,t}^{max}(a)$ is given by:

$$\begin{aligned} p_{j,t}^{max}(a) &= \begin{cases} p_{j-,t} + a - (d_{j-,j,t}^{tech} - a), & \text{for } d_{j-,j,t}^{tech} - a_{j,t} \leq a < a^*; \\ p_{j+,t} + d_{j,j+,t}^{tech}, & \text{for } a^* \leq a < d_{j-,j,t}^{tech}; \\ p_{j+,t} + (d_{j,j+,t}^{tech} - (a - d_{j-,j,t}^{tech})) - (a - d_{j-,j,t}^{tech}), & \text{for } d_{j-,j,t}^{tech} \leq a < d_{j-,j,t}^{tech} + b_{j,t}. \end{cases} \\ &= \begin{cases} p_{j-,t} - d_{j-,j,t}^{tech} + 2a, & \text{for } d_{j-,j,t}^{tech} - a_{j,t} \leq a < a^*; \\ p_{j+,t} + d_{j,j+,t}^{tech}, & \text{for } a^* \leq a < d_{j-,j,t}^{tech}; \\ p_{j+,t} + d_{j,j+,t}^{tech} + 2d_{j-,j,t}^{tech} - 2a, & \text{for } d_{j-,j,t}^{tech} \leq a < d_{j-,j,t}^{tech} + b_{j,t}. \end{cases} \end{aligned} \quad (\text{A.2})$$

In the first part till a^* the left relevant market $j-$ determines the height of the maximum price. After a^* the right relevant market $j+$ sets the maximum price in j because after that point consumers have a greater utility by choosing market $j+$ instead of $j-$ as an alternative. Between a^* and $d_{j-,j,t}^{tech}$ prices on j do not depend on the location of the consumer and have to be lower than $p_{j+,t} + d_{j,j+,t}^{tech}$ as the consumers would otherwise change to market $j+$. After that range consumers would only accept a lower price because their location gets closer to $j+$.

Analogously to (A.2) the maximum price $p_{j-,t}^{max}(a)$ for the second case $a^* > d_{j-,j,t}^{tech}$

is formulated:

$$p_{j,t}^{max}(a) = \begin{cases} p_{j-,t} - d_{j-,j,t}^{tech} + 2a, & \text{for } d_{j-,j,t}^{tech} - a_{j,t} \leq a < d_{j-,j,t}^{tech}; \\ p_{j-,t} + d_{j-,j,t}^{tech}, & \text{for } d_{j-,j,t}^{tech} \leq a < a^*; \\ p_{j+,t} + d_{j+,j,t}^{tech} + 2d_{j-,j,t}^{tech} - 2a, & \text{for } a^* \leq a < d_{j-,j,t}^{tech} + b_{j,t}. \end{cases} \quad (\text{A.3})$$

With the maximum price it is possible to calculate the consumer surplus for every customer as the space between the actual and the maximum price of the demand function. At this point it is important to differentiate between the range of attracted consumers which are active consumers on sub-market j indicated by $\bar{a}_{j,t}$ and $\bar{b}_{j,t}$ from equation (4.14) and the range that is necessary to compute the maximum price given by $a_{j,t}$ and $b_{j,t}$. This ranges will be different, if prices of the last period (needed for $\bar{a}_{j,t}$ and $\bar{b}_{j,t}$) and prices of this period (needed for $a_{j,t}$ and $b_{j,t}$) change. For the consumer surplus the smaller value $\min\{\bar{a}_{j,t}, a_{j,t}\}$ respectively $\min\{\bar{b}_{j,t}, b_{j,t}\}$ is relevant, because all consumers behind $a_{j,t}$ and $b_{j,t}$ would not choose sub-market j (what means that they already pay the maximum price) and all consumers buying on market j are restricted by the range $[\bar{a}_{j,t}, \bar{b}_{j,t}]$.

Therefore, the aggregated consumer surplus $CS_{j,t}$ for all consumers active on market j is given by:

$$\begin{aligned} CS_{j,t} &= \int_{d_{j-,j,t}^{tech} - \min\{\bar{a}_{j,t}, a_{j,t}\}}^{d_{j-,j,t}^{tech} + \min\{\bar{b}_{j,t}, b_{j,t}\}} \left(\int_{p_{j,t}}^{p_{j,t}^{max}(a)} \left(\frac{B_m}{p} \right) dp \right) da \\ &= B_m \int_{d_{j-,j,t}^{tech} - \min\{\bar{a}_{j,t}, a_{j,t}\}}^{d_{j-,j,t}^{tech} + \min\{\bar{b}_{j,t}, b_{j,t}\}} (\ln(p_{j,t}^{max}(a)) - \ln(p_{j,t})) da \\ &= B_m \int_{d_{j-,j,t}^{tech} - \min\{\bar{a}_{j,t}, a_{j,t}\}}^{d_{j-,j,t}^{tech} + \min\{\bar{b}_{j,t}, b_{j,t}\}} \ln(p_{j,t}^{max}(a)) \cdot da \\ &\quad - B_m \cdot \ln(p_{j,t}) \cdot (\min\{\bar{a}_{j,t}, a_{j,t}\} + \min\{\bar{b}_{j,t}, b_{j,t}\}) \end{aligned} \quad (\text{A.4})$$

After the calculation of a^* from (A.1) the equation (A.2) (or respectively (A.3)) has to be inserted into (A.4). The integral in the formula can be solved and it is possible to compute the consumer surplus for each sub-market. Thus, the consumer surplus of the industry CS_t is the sum over all sub-market specific values: $CS_t = \sum_j CS_{j,t}$.

Furthermore, it is important to mention that the consumer surplus is related to the current technology space and current prices. Besides, the calculation of the budgets $B_{j,t}$ is based on the actual technology space but on the prices of *last* period. The consumer surplus does not take into account markets which are dominated in the computation of the budget.

The calculation of the consumer surplus for every sub-market was implemented with the help of a function which calculates the general solution to the following integral:

$$\begin{aligned}
& \int_{a_1}^{a_2} \ln(c_1 + c_2 \cdot a) da \\
&= \left[\frac{1}{c_2} (c_1 + c_2 \cdot a) \cdot (\ln(c_1 + c_2 \cdot a) - 1) \right]_{a_1}^{a_2} \\
&= \frac{1}{c_2} [(c_1 + c_2 \cdot a_2) \cdot (\ln(c_1 + c_2 \cdot a_2) - 1) \\
&\quad - (c_1 + c_2 \cdot a_1) \cdot (\ln(c_1 + c_2 \cdot a_1) - 1)] \tag{A.5}
\end{aligned}$$

Knowing the solution to the above integral, the calculation of the consumer surplus in the two cases given by (A.2) and (A.3) inserted into (A.4) is possible. For middle values of a the maximum price is independent of a and, thus, the integration is straightforward.

For $a^* \leq d_{j-,j,t}^{tech}$:

$$\begin{aligned}
CS_{j,t} &= B_m \int_{d_{j-,j,t}^{tech} - \min\{\bar{a}_{j,t}, a_{j,t}\}}^{d_{j-,j,t}^{tech} + \min\{\bar{b}_{j,t}, b_{j,t}\}} \ln(p_{j,t}^{max}(a)) \cdot da \\
&\quad - B_m \cdot \ln(p_{j,t}) \cdot (\min\{\bar{a}_{j,t}, a_{j,t}\} + \min\{\bar{b}_{j,t}, b_{j,t}\}) \\
&= B_m \int_{d_{j-,j,t}^{tech} - \min\{\bar{a}_{j,t}, a_{j,t}\}}^{a^*} \ln(p_{j-,t} - d_{j-,j,t}^{tech} + 2a) \cdot da \\
&\quad + B_m \int_{a^*}^{d_{j-,j,t}^{tech}} \ln(p_{j+,t} + d_{j,j+,t}^{tech}) \cdot da \\
&\quad + B_m \int_{d_{j-,j,t}^{tech}}^{d_{j-,j,t}^{tech} + \min\{\bar{b}_{j,t}, b_{j,t}\}} \ln(p_{j+,t} + d_{j,j+,t}^{tech} + 2d_{j-,j,t}^{tech} - 2a) \cdot da \\
&\quad - B_m \cdot \ln(p_{j,t}) \cdot (\min\{\bar{a}_{j,t}, a_{j,t}\} + \min\{\bar{b}_{j,t}, b_{j,t}\}) \tag{A.6}
\end{aligned}$$

For $a^* > d_{j-,j,t}^{tech}$:

$$\begin{aligned}
CS_{j,t} &= B_m \int_{d_{j-,j,t}^{tech} - \min\{\bar{a}_{j,t}, a_{j,t}\}}^{d_{j-,j,t}^{tech} + \min\{\bar{b}_{j,t}, b_{j,t}\}} \ln(p_{j,t}^{max}(a)) \cdot da \\
&\quad - B_m \cdot \ln(p_{j,t}) \cdot (\min\{\bar{a}_{j,t}, a_{j,t}\} + \min\{\bar{b}_{j,t}, b_{j,t}\}) \\
&= B_m \int_{d_{j-,j,t}^{tech} - \min\{\bar{a}_{j,t}, a_{j,t}\}}^{d_{j-,j,t}^{tech}} \ln(p_{j-,t} - d_{j-,j,t}^{tech} + 2a) \cdot da \\
&\quad + B_m \int_{d_{j-,j,t}^{tech}}^{a^*} \ln(p_{j-,t} + d_{j-,j,t}^{tech}) \cdot da \\
&\quad + B_m \int_{a^*}^{d_{j-,j,t}^{tech} + \min\{\bar{b}_{j,t}, b_{j,t}\}} \ln(p_{j+,t} + d_{j+,t}^{tech} + 2d_{j-,j,t}^{tech} - 2a) \cdot da \\
&\quad - B_m \cdot \ln(p_{j,t}) \cdot (\min\{\bar{a}_{j,t}, a_{j,t}\} + \min\{\bar{b}_{j,t}, b_{j,t}\}) \tag{A.7}
\end{aligned}$$

In the special case that the industry consists only of one sub-market or one sub-market dominates all others, the maximum price should depend on the highest price consumers were already willing to pay. If there are other (not relevant) markets, the highest price in the last period is taken. Otherwise all last periods are considered.

$$p_t^{max} = \begin{cases} \max_{j,t}\{p_{j,t}\}, & \text{if } m_t = 1; \\ \max_j\{p_{j,t-1}\}, & \text{if } m_t > 1 \text{ and only one relevant sub-market.} \end{cases} \tag{A.8}$$

With the total circumference of the technological circle d_t^{tech} analogously the consumer surplus in this case can be calculated as:

$$\begin{aligned}
CS_{j,t} &= B_m \int_0^{d_t^{tech}} \ln(p_t^{max}) \cdot da - B_m \cdot \ln(p_{j,t}) \cdot (d_t^{tech}) \\
&= B_m \cdot d_t^{tech} (\ln(p_t^{max}) - \ln(p_{j,t})) \tag{A.9}
\end{aligned}$$

A.2 Parameter Settings

Parameter	Value	Parameter	Value
T	200	Runs	100
n	10	c	0.935
d	0.94	e	0.95
τ	3	τ_{ex}	3
x_{min}	0.5	ρ	0
c^{min}	0.3	c^{ini}	0.5
c^{geo}	0	B_m	3
α_i	[3, 4]	β_i	[0.75, 0.85]
$\kappa_{i,en}$	[0, 1]	F_i	[0.2, 0.4]
$\kappa_{i,ex}$	[0, 0.1]	$\kappa_{i,S}$	[0, 1]
$\delta_{i,SP}$	[0, 1]	$\delta_{i,\Pi}$	[0, 1]
$\delta_{i,RD}$	[0, 1]	$\delta_{i,T}$	[0, 1]
q_i^{prod}	[0.24, 0.32]	q_i^{proc}	[0.08, 0.16]

Table A.1: Parameter settings for the standard case.

If the parameters are indicated as an interval, the values for the parameters are chosen uniformly distributed in the given range for every simulation run.

Parameter	Value	Parameter	Value
RD^0	0.2	σ_0^2	0.0025
d_0^{tech}	2	σ_{tech}^2	0.25
S^0	10	m_0	5

Table A.2: Initial conditions in the standard case.

The starting value for firm-specific knowledge for process innovations and the resulting technological distances are drawn from a normal distribution with the corresponding mean and variance.

Scenario	$\delta_{i,\Pi}$	$\delta_{i,T}$
Balanced or Standard	[0,1]	[0,1]
Profit-Oriented	[0,1]	[0,0.2]
Knowledge-Oriented	[0,0.2]	[0,1]
Random	irrelevant	irrelevant

Table A.3: Parameter setting for the firm strategy scenarios.

	Schumpeter Mark I	Schumpeter Mark II
External Institution	Yes ($I_{j,t}^{ext} \in [1, 2], \omega^{ext} = 1,$ $\alpha^{ext} \in [3, 4], \beta^{ext} \in [0.75, 0.85]$)	No
Process Innovations	Low Investments ($q_i^{proc} \in [0.02, 0.04]$)	High Investments ($q_i^{proc} \in [0.08, 0.16]$)
Product Innovations	Easier and more radical ($c = 0.93, d = 0.935, e = 0.94$)	Higher thresholds and mostly incremental ($c = 0.935, d = 0.94, e = 0.95$)
Initial Knowledge for new Technologies	Non-Cumulative ($RD_j^0 \in [RD^0, 0.5]$)	Cumulative ($RD_j^0 = \frac{RD_{i,j-1,t}^{proc} + RD_{i,j+1,t}^{proc}}{2}$)
Patent Length	Short Patent Protection ($\tau = 1$)	Long Patent Protection ($\tau = 10$)
Knowledge Spillover	High external and low internal Spillovers ($\omega_{ex} = 0.1, \omega_{in} = 0.1$)	No external, but high internal Spillovers ($\omega_{ex} = 0, \omega_{in} = 1$)
Number of Firms in the Industry	Many ($n = 10$)	Few ($n = 5$)

Table A.4: The corresponding parameters for the representation of technological regimes.

Policy	Name	Parameters
1	Enhance Incentive for Agglomeration	$R \in [-0.002, -0.004], \delta_{i,R} \in [0, 1],$ $I_{j,t}^{ext} \in [0.1, 0.2], \omega^{ext} = 1,$ $\alpha^{ext} \in [3, 4],$ and $\beta^{ext} \in [0.75, 0.85]$
2	Foster Learning through Knowledge Flows	$\omega_{ex} = 1.2, I_{j,t}^{ext} \in [0.1, 0.2], \omega^{ext} = 1,$ $\alpha^{ext} \in [3, 4],$ and $\beta^{ext} \in [0.75, 0.85]$
3	Increase Appropriability	$\tau \in [5, 10]$ and $B_m \in [3, 4]$
4	Control Specialization of Agglomeration	$I_{i,j,t}^{proc} = I_{i,j,t}^{proc} + [0.3, 0.6],$ if $(1 \leq t \leq [50, 100])$ $\wedge d_{i,t}^{geo} = 0 \wedge j = \max_l \{RD_{i,l,t}^{proc}\}$ and $I_{i,j,t}^{prod} = I_{i,j,t}^{prod} + [0.3, 0.6],$ if $([100, 150] \leq t \leq 200)$ $\wedge d_{i,t}^{geo} = 0 \wedge j = \max_l \{d_{l-1,l,t}^{tech} + d_{l,l+1,t}^{tech}\}$

Table A.5: The corresponding parameters for the policy measures.

For policy 1 we alter equation (6.3) to the term shown in equation (A.10). We do this because in the standard case production cost inside and outside the core do not differ and, therefore, are not taken into account for the evaluation of geographical location. The difference between the two equations is that in equation (A.10) equal costs don't have an influence on the evaluation as the term for cost becomes equal to 0.5. The lower the cost at the core due to the subsidy the higher is the incentive for core.

$$\begin{aligned}
v_{i,t}^{geo} &= \left[\mathbb{E} \left(\frac{RD_{i,j,t}^{proc}}{RD_{j,t}^{proc}} \right) \right]^{\frac{\delta_{i,RD}}{\delta_{i,RD} + \delta_{i,SP} + \delta_{i,R}}} \\
&\cdot \left[\mathbb{E} \left(\frac{SP_{i,j,t}^{proc}(d_{i,j,t}^{geo} = 1)}{SP_{i,j,t}^{proc}(d_{i,j,t}^{geo} = 0)} \right) \right]^{\frac{\delta_{i,SP}}{\delta_{i,RD} + \delta_{i,SP} + \delta_{i,R}}} \\
&\cdot \left[\max \left\{ \mathbb{E} \left(\frac{c_{i,j,t}(d_{i,t}^{geo} = 0)}{c_{i,j,t}(d_{i,t}^{geo} = 1)} \right) - \frac{1}{2}, 0 \right\} \right]^{\frac{\delta_{i,R}}{\delta_{i,RD} + \delta_{i,SP} + \delta_{i,R}}} \tag{A.10}
\end{aligned}$$

Further, the subsidy in policy 1 does not depend on the number of firms at the core as all cluster firms get the same amount for every produced good. Thus we use the following adapted equation (A.11).

$$c_{i,j,t} = c^{ini} [c^{min} + (1 - c^{min})(1 - RD_{i,j,t}^{proc})] + (1 - d_{i,t}^{geo}) \cdot R \tag{A.11}$$

For policy 3 only integers in the interval for the length of the patent τ are considered.

A.3 Statistical Tests

One way to examine the robustness of the simulation results is to apply a two-sample Wilcoxon rank sum test (sometimes called Mann-Whitney U-test, Mann-Whitney-Wilcoxon, or Wilcoxon-Mann-Whitney test), which is based solely on the order in which the observations from the two samples fall. This test was proposed initially by Wilcoxon (1945) and extended by Mann and Whitney (1947), see also Feltovich (2003) for a recent discussion. The Wilcoxon rank sum test requires the two samples to be independent and the observations to be ordinal or continuous measurements. The main advantage of this test is that the observations need not to come from normal distributions.

In the following the null and alternative hypothesis are formulated to compare the outcome of several runs with different parameter settings. The results of several simulation runs are listed according to the considered section and the tests were performed with the help of the statistical software S-Plus. Generally, one rejects the null hypothesis if the p-value is smaller than or equal to the assumed significance level.

Section 6.2:

1. Number of Firms at the core at $T = 200$:
 $H0$: Standard Scenario \leq Additional Cost at the core
 $H1$: Standard Scenario $>$ Additional Cost at the core
Results: $Z = 3.7122$, p-value = 0.0001
2. Number of Firms at the core at $T = 200$:
 $H0$: High Spillover \geq Low Spillover
 $H1$: High Spillover $<$ Low Spillover
Results: $Z = -1.6929$, p-value = 0.0452
3. Number of Firms at the core at $T = 200$:
 $H0$: High Spillover \geq Standard Scenario
 $H1$: High Spillover $<$ Standard Scenario
Results: $Z = -1.5351$, p-value = 0.0624
4. Number of Firms at the core at $T = 200$:
 $H0$: Standard Scenario \geq Low Spillover
 $H1$: Standard Scenario $<$ Low Spillover
Results: $Z = -0.2218$, p-value = 0.4123

5. Sum of Knowledge Spillovers over all Firms in $T = 100$:
H0: Internal Knowledge Spillovers \geq External Knowledge Spillovers
H1: Internal Knowledge Spillovers $<$ External Knowledge Spillovers
Results: $Z = -1.9751$, p-value = 0.0241
6. Sum of Knowledge Spillovers over all Firms in $T = 400$:
H0: Internal Knowledge Spillovers \leq External Knowledge Spillovers
H1: Internal Knowledge Spillovers $>$ External Knowledge Spillovers
Results: $Z = 3.5538$, p-value = 0.0002
7. Average Aggregated Profits at $T = 200$:
H0: Core \geq Periphery
H1: Core $<$ Periphery
Results: $Z = -10.7228$, p-value = 0

Section 6.3:

1. Industry Specialization in Location at $T = 200$:
H0: Knowledge-Oriented \leq Standard Scenario
H1: Knowledge-Oriented $>$ Standard Scenario
Results: $Z = 4.2185$, p-value = 0
2. Industry Specialization in Location at $T = 200$:
H0: Standard Scenario \leq Profit-Oriented
H1: Standard Scenario $>$ Profit-Oriented
Results: $Z = 5.0175$, p-value = 0
3. Industry Specialization in Location at $T = 200$:
H0: Standard Scenario = Random
H1: Standard Scenario \neq Random
Results: $Z = 0.959$, p-value = 0.3375
4. Firm Specialization in Height at $T = 200$:
H0: Profit-Oriented \leq Standard Scenario
H1: Profit-Oriented $>$ Standard Scenario
Results: $Z = 4.8978$, p-value = 0
5. Firm Specialization in Height at $T = 200$:
H0: Standard Scenario \leq Random
H1: Standard Scenario $>$ Random
Results: $Z = 1.5198$, p-value = 0.0643

6. Firm Specialization in Height at $T = 200$:
H0: Random \leq Knowledge-Oriented
H1: Random $>$ Knowledge-Oriented
Results: $Z = 1.6933$, p-value = 0.0904
7. Average Firm Profits at $T = 200$:
H0: Knowledge-Oriented \leq Random
H1: Knowledge-Oriented $>$ Random
Results: $Z = -3.3817$, p-value = 0.0004
8. Average Firm Profits at $T = 200$:
H0: Knowledge-Oriented \leq Standard Scenario
H1: Knowledge-Oriented $>$ Standard Scenario
Results: $Z = 4.1208$, p-value = 0
9. Average Firm Profits at $T = 200$:
H0: Random \leq Standard Scenario
H1: Random $>$ Standard Scenario
Results: $Z = 0.5168$, p-value = 0.3027
10. Average Firm Profits at $T = 200$:
H0: Random \leq Profit-Oriented
H1: Random $>$ Profit-Oriented
Results: $Z = 1.653$, p-value = 0.0492
11. Average Firm Profits at $T = 200$:
H0: Standard Scenario \leq Profit-Oriented
H1: Standard Scenario $>$ Profit-Oriented
Results: $Z = 1.3084$, p-value = 0.0954

Section 7.1:

1. Maximum Knowledge for Process Innovations at $T = 200$:
H0: Periphery \leq Core
H1: Periphery $>$ Core
Results: $Z = -6.0511$, p-value = 0
2. Average Knowledge for Process Innovations at $T = 200$:
H0: Periphery \leq Core
H1: Periphery $>$ Core
Results: $Z = 5.4378$, p-value = 0

3. Number of Successful Product Innovations till $T = 200$:
H0: Periphery \leq Core
H1: Periphery $>$ Core
Results: $Z = 8.5306$, p-value = 0
4. Radical Product Innovations till $T = 200$:
H0: 0% core \leq 50% core
H1: 0% core $>$ 50% core
Results: $Z = 2.985$, p-value = 0.0014
5. Radical Product Innovations till $T = 200$:
H0: 50% core \leq Standard / Variable
H1: 50% core $>$ Standard / Variable
Results: $Z = 1.4902$, p-value = 0.0681
6. Radical Product Innovations till $T = 200$:
H0: Standard / Variable = 100% core
H1: Standard / Variable \neq 100% core
Results: $Z = -0.4507$, p-value = 0.6522
7. Radical Product Innovations till $T = 200$:
H0: 0% core \leq 100% core
H1: 0% core $>$ 100% core
Results: $Z = 3.872$, p-value = 0.0001
8. Incremental Product Innovations till $T = 200$:
H0: 50% core \leq 0% core
H1: 50% core $>$ 0% core
Results: $Z = -1.858$, p-value = 0.0316
9. Incremental Product Innovations till $T = 200$:
H0: 100% core \leq 50% core
H1: 100% core $>$ 50% core
Results: $Z = 7.9716$, p-value = 0
10. Incremental Product Innovations till $T = 200$:
H0: 100% core \leq Standard / Variable
H1: 100% core $>$ Standard / Variable
Results: $Z = 9.6065$, p-value = 0
11. Incremental Product Innovations till $T = 200$:
H0: 50% core \leq Standard / Variable

- H1: 50% core > Standard / Variable*
Results: Z = -3.3996, p-value = 0.0003
12. Incremental Product Innovations till $T = 200$:
H0: 0% core = Standard / Variable
H1: 0% core \neq Standard / Variable
Results: Z = 0.8753, p-value = 0.3814
13. Maximum Process Innovations at $T = 200$:
H0: 0% core \leq 50% core
H1: 0% core > 50% core
Results: Z = 5.3486, p-value = 0
14. Maximum Process Innovations at $T = 200$:
H0: 50% core \leq Standard / Variable
H1: 50% core > Standard / Variable
Results: Z = 1.4196, p-value = 0.0779
15. Maximum Process Innovations at $T = 200$:
H0: Standard / Variable \leq 100% core
H1: Standard / Variable > 100% core
Results: Z = 3.0298, p-value = 0.0012
16. Average Process Innovations at $T = 100$:
H0: 100% core \leq Standard / Variable
H1: 100% core > Standard / Variable
Results: Z = 4.5985, p-value = 0
17. Average Process Innovations at $T = 100$:
H0: Standard / Variable \leq 50% core
H1: Standard / Variable > 50% core
Results: Z = 2.2223, p-value = 0.0131
18. Average Process Innovations at $T = 100$:
H0: 50% core \leq 0% core
H1: 50% core > 0% core
Results: Z = 4.3517, p-value = 0
19. Average Aggregated Profits till $T = 200$:
H0: 0% core \leq Standard / Variable
H1: 0% core > Standard / Variable
Results: Z = 5.318, p-value = 0

20. Average Aggregated Profits till $T = 200$:
H0: Standard / Variable \leq 100% core
H1: Standard / Variable $>$ 100% core
Results: $Z = 3.2045$, p-value = 0.0007
21. Average Aggregated Profits till $T = 200$:
H0: 100% core \leq Standard / Variable - Firms at the core
H1: 100% core $>$ Standard / Variable - Firms at the core
Results: $Z = -6.9747$, p-value = 0
22. Average Aggregated Profits till $T = 200$:
H0: Standard / Variable - Firms on the periphery \leq 0% core
H1: Standard / Variable - Firms on the periphery $>$ 0% core
Results: $Z = 0.722$, p-value = 0.2351
23. Average Aggregated Profits till $T = 200$:
H0: 0% core \leq 50% core
H1: 0% core $>$ 50% core
Results: $Z = 4.6363$, p-value = 0
24. Average Aggregated Profits till $T = 200$:
H0: 50% core \leq 100% core
H1: 50% core $>$ 100% core
Results: $Z = 3.6761$, p-value = 0.0001
25. Consumer Surplus at $T = 200$:
H0: 0% core \leq 50% core
H1: 0% core $>$ 50% core
Results: $Z = 2.5521$, p-value = 0.0054
26. Consumer Surplus at $T = 200$:
H0: 50% core \leq 100% core
H1: 50% core $>$ 100% core
Results: $Z = 1.8338$, p-value = 0.0333
27. Consumer Surplus at $T = 200$:
H0: 50% core \leq Standard / Variable
H1: 50% core $>$ Standard / Variable
Results: $Z = -1.5039$, p-value = 0.0663
28. Consumer Surplus at $T = 200$:
H0: 100% core \leq Standard / Variable

- H1: 100% core > Standard / Variable*
Results: Z = -1.3823, p-value = 0.0834
29. Producer Surplus at $T = 200$:
H0: 0% core \leq 50% core
H1: 0% core > 50% core
Results: Z = 1.3915, p-value = 0.082
30. Producer Surplus at $T = 200$:
H0: 50% core \leq Standard / Variable
H1: 50% core > Standard / Variable
Results: Z = 1.5039, p-value = 0.0663
31. Producer Surplus at $T = 200$:
H0: Standard / Variable \leq 100% core
H1: Standard / Variable > 100% core
Results: Z = -0.9871, p-value = 0.8382
32. Producer Surplus at $T = 200$:
H0: 0% core \leq 100% core
H1: 0% core > 100% core
Results: Z = 1.383, p-value = 0.0833
33. Welfare at $T = 200$:
H0: 0% core \leq 50% core
H1: 0% core > 50% core
Results: Z = 1.7702, p-value = 0.0383
34. Welfare at $T = 200$:
H0: 50% core \leq Standard / Variable
H1: 50% core > Standard / Variable
Results: Z = 1.4783, p-value = 0.0697
35. Welfare at $T = 200$:
H0: Standard / Variable \leq 100% core
H1: Standard / Variable > 100% core
Results: Z = -0.6194, p-value = 0.7322
36. Welfare at $T = 200$:
H0: 0% core \leq 100% core
H1: 0% core > 100% core
Results: Z = 2.2308, p-value = 0.0128

Section 7.2:

1. Number of Incremental Product Innovations over the simulated periods:
H0: Schumpeter Mark I \geq Schumpeter Mark II
H1: Schumpeter Mark I $<$ Schumpeter Mark II
Results: $Z = 7.8566$, p-value = 0
2. Number of Radical Product Innovations over the simulated periods:
H0: Schumpeter Mark I \leq Schumpeter Mark II
H1: Schumpeter Mark I $>$ Schumpeter Mark II
Results: $Z = 4.603$, p-value = 0
3. best-practice for Process Innovation at $T = 50$:
H0: Schumpeter Mark I \geq Schumpeter Mark II
H1: Schumpeter Mark I $<$ Schumpeter Mark II
Results: $Z = 7.6393$, p-value = 0
4. Average Level of Process Innovations at $T = 200$:
H0: Schumpeter Mark I \geq Schumpeter Mark II
H1: Schumpeter Mark I $<$ Schumpeter Mark II
Results: $Z = 8.1426$, p-value = 0
5. Average Market Concentration at $T = 200$:
H0: Schumpeter Mark I \geq Schumpeter Mark II
H1: Schumpeter Mark I $<$ Schumpeter Mark II
Results: $Z = 7.4242$, p-value = 0
6. Industry Concentration at $T = 200$:
H0: Schumpeter Mark I \leq Schumpeter Mark II
H1: Schumpeter Mark I $>$ Schumpeter Mark II
Results: $Z = 5.494$, p-value = 0
7. Average Firm Specialization in Knowledge at $T = 200$:
H0: Schumpeter Mark I \leq Schumpeter Mark II
H1: Schumpeter Mark I $>$ Schumpeter Mark II
Results: $Z = 11.5902$, p-value = 0
8. Average Firm Specialization in Location at $T = 200$:
H0: Schumpeter Mark I \leq Schumpeter Mark II
H1: Schumpeter Mark I $>$ Schumpeter Mark II
Results: $Z = 10.5225$, p-value = 0

Section 7.3:

1. Number of Firms at the core at $T = 200$:
H0: Policy 1 \leq Standard
H1: Policy 1 $>$ Standard
Results: $Z = 9.4964$, p-value = 0
2. Number of Firms at the core at $T = 200$:
H0: Policy 2 \geq Standard
H1: Policy 2 $<$ Standard
Results: $Z = -11.6066$, p-value = 0
3. Number of Firms at the core at $T = 200$:
H0: Policy 3 = Standard
H1: Policy 3 \neq Standard
Results: $Z = 1.0198$, p-value = 0.3078
4. Number of Firms at the core at $T = 200$:
H0: Policy 4 \leq Standard
H1: Policy 4 $>$ Standard
Results: $Z = 2.4553$, p-value = 0.007
5. Sum of all Knowledge Spillovers at $T = 200$:
H0: Policy 1 \leq Standard
H1: Policy 1 $>$ Standard
Results: $Z = 9.5146$, p-value = 0
6. Sum of all Knowledge Spillovers at $T = 200$:
H0: Policy 2 \leq Standard
H1: Policy 2 $>$ Standard
Results: $Z = 5.0065$, p-value = 0
7. Sum of all Knowledge Spillovers at $T = 200$:
H0: Policy 4 = Policy 1
H1: Policy 4 \neq Policy 1
Results: $Z = 0.7489$, p-value = 0.4539
8. Sum of all Knowledge Spillovers at $T = 200$:
H0: Policy 2 = Policy 3
H1: Policy 2 \neq Policy 3
Results: $Z = 1.5674$, p-value = 0.117
9. Sum of all Knowledge Spillovers at $T = 200$:
H0: Policy 1 \leq Policy 2

- H1*: Policy 1 > Policy 2
Results: $Z = 6.8855$, p-value = 0
10. Average Level of aggregated Profits till $T = 200$:
H0: Policy 3 \leq Policy 4
H1: Policy 3 > Policy 4
Results: $Z = 4.0927$, p-value = 0
11. Average Level of aggregated Profits till $T = 200$:
H0: Policy 4 = Policy 2
H1: Policy 4 \neq Policy 2
Results: $Z = -0.4911$, p-value = 0.6233
12. Average Level of aggregated Profits till $T = 200$:
H0: Policy 4 = Policy 1
H1: Policy 4 \neq Policy 1
Results: $Z = -0.7281$, p-value = 0.4665
13. Average Level of aggregated Profits till $T = 200$:
H0: Policy 4 = Standard
H1: Policy 4 \neq Standard
Results: $Z = 0.5363$, p-value = 0.5917
14. Specialization of the Core at $T = 200$:
H0: Policy 3 = Standard
H1: Policy 3 \neq Standard
Results: $Z = 0.2407$, p-value = 0.8098
15. Specialization of the Core at $T = 200$:
H0: Policy 2 \leq Standard
H1: Policy 2 > Standard
Results: $Z = 4.4808$, p-value = 0
16. Specialization of the Core at $T = 200$:
H0: Policy 4 \geq Standard
H1: Policy 4 < Standard
Results: $Z = -1.9266$, p-value = 0.027
17. Specialization of the Core at $T = 200$:
H0: Policy 1 \geq Policy 4
H1: Policy 1 < Policy 4
Results: $Z = -5.2313$, p-value = 0

18. Specialization of the Core at $T = 200$:
H0: Policy 1 \geq Policy 4
H1: Policy 1 $<$ Policy 4
Results: $Z = -5.2313$, p-value = 0
19. Total Policy Cost till $T = 200$:
H0: Policy 2 \leq Policy 4
H1: Policy 2 $>$ Policy 4
Results: $Z = 8.999$, p-value = 0
20. Total Policy Cost till $T = 200$:
H0: Policy 3 \leq Policy 2
H1: Policy 3 $>$ Policy 2
Results: $Z = 7.1567$, p-value = 0
21. Total Policy Cost till $T = 200$:
H0: Policy 1 \leq Policy 3
H1: Policy 1 $>$ Policy 3
Results: $Z = 7.0663$, p-value = 0
22. Welfare of the Industry at $T = 200$:
H0: Policy 3 \leq Policy 4
H1: Policy 3 $>$ Policy 4
Results: $Z = 2.0549$, p-value = 0.0199
23. Welfare of the Industry at $T = 200$:
H0: Policy 4 \leq Policy 1
H1: Policy 4 $>$ Policy 1
Results: $Z = 1.3585$, p-value = 0.0871
24. Welfare of the Industry at $T = 200$:
H0: Policy 1 \leq Standard
H1: Policy 1 $>$ Standard
Results: $Z = 2.1868$, p-value = 0.0144
25. Welfare of the Industry at $T = 200$:
H0: Policy 2 = Standard
H1: Policy 2 \neq Standard
Results: $Z = 1.1044$, p-value = 0.2694

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