The 50 best Austrian innovations: Lessons learned from the perspective of complexity theory

Dr. Karl-Heinz Leitner
ARC systems research, Austria

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Abstract

50 major Austrian industrial innovations developed between 1975 and 2000 have been studied in a research project to reveal success factors of radical innovations based on a case study approach (Leitner 2003). Based on this empirical data the innovation process in different industries should be analysed from the complexity theory perspective for the question of the fuzzy front end of innovation. The question of the sources of innovation, the strategic intentions in the early phase, the incentives for setting up an innovation and the configuration of the innovations teams will be studied based on a conceptual framework. This framework rests on the insights of the complexity theory, which stresses that self-organisation, emergence and semi-structures are important elements for successful innovations. According to this paradigm neither too much nor too little structure are stimulating creativity, innovation and the formation of complementary innovation teams in firms. The paper shows that chance, self-organisation and strategic intentions are equally important for many radical innovations developed by Austrian firms.

Key words: innovation models, complexity theory, self-organisation, successful innovations
Introduction

In the past two decades complexity theory has delivered some interesting findings about the dynamics of complex systems which are also of relevance for innovation researchers. While no commonly accepted ground theory about complexity exists yet, rather different approaches have emerged in various science disciplines dealing with different forms of complex systems and complex phenomena. The complexity theory deals with the dynamics of complex systems, which can be found in physics, biology but also in society and the economy.

In recent years some researchers have adopted concepts of the complexity theory for the social sciences and economics and a few innovation researchers have already integrated the new ideas. Evolutionary economists like Foster and Metcalfe (2001) or Ziman (2000) as well as organisational researchers such as Anderson (1999) or McKelvey (1999) call for the integration of the complexity theory for questions in relation to organisational change, technological development and innovation. Evolutionary economics have traditionally taken over ideas from biology, insofar it is a logical step to adopt new ideas from the complexity theory which have gained much attention within the evolutionary biology. Finally, some researchers such as Brown and Eisenhardt (1997) or Cunha and Gomes (2003) have also applied concepts of complexity theory for the development of innovation models. These approaches replace traditional linear models of the innovation or new product development processes (see Rothwell 1994 for an overview) and focuses on the emergent and non-linear character of the innovation process.

For innovation researchers the concepts of self-organisation and emergence, - important features of complex systems according to the complexity theory -, are probably the most interesting ones. Academics have tried to apply these concepts for managerial and organisational questions, however no commonly accepted understanding about which business phenomena and elements of the innovation process could be interpreted as emergent or self-organising exists yet. The implications of the new complexity perspective for the management are seldom elaborated in more detail and are sometimes rather superficial, for instance the conclusion that organisational change and innovations are difficult to plan and control.

Modern innovation management reflects the process orientation and co-operative nature of innovation. Innovation is recognized as an interactive process between a diversity of actors (R&D, marketing, production, sales, etc.). While evolutionary approaches emphasise variation and selection phases in the innovation process, systemic approaches recognize the importance of knowledge-based interactions whereby the social structure of the actor network and the exchange of knowledge in terms of accessibility and speed, i.e. the adoption and exchange structure within a firm’s innovation system, is vital. Instruments for innovation management have partly been based on innovation or new product development models which have been
introduced in the past three decades. Here, for instance the innovation funnel by Clark and Wheelwright (1993) or the stage-gate-model by Cooper (1987) gained much attention in the industry. However, these models do not deliver answers for many new challenges in dynamic environments, are sometimes oversimplifying, are often difficult to apply and can even harm creativity. The findings of the complexity theory offer new explanations for the phenomenon of innovation and are promising as concerns the development of a new innovation model. The elements of such a model, which stresses that self-organisations, emergence and flexibility are important, will be presented and illustrated based on empirical findings of a study about 50 major Austrian innovations (Leitner 2003).

In the paper first recent contributions of innovation and organization researchers who have already adopted the complexity science perspective will be reviewed. Second, the principles of a complexity-based innovation process model will be presented. Afterwards, empirical evidence from a complexity-based perspective on innovation processes is delivered for some case studies of successful Austrian innovations.

The innovation process from the complexity theory perspective: a review

Innovation process models: status quo

In the past decades, different innovation models were presented in the literature and some classifications have been proposed. Rothwell (1994), for instance, separates five models of innovation, which he defines as i) technology push, ii) market pull, iii) coupled, iv) interactive, and finally as v) integration and networking model1. The later one focuses on networking between different actors inside and outside the firm and is enabled by the new information technologies. Sundby (1995), in contrast, separates three paradigms within the innovation theory: the entrepreneurship, technology-economic and strategic innovation paradigm. These three paradigms stress the role of the individual entrepreneur and inventor, the role of new technologies or the role of strategic actions, especially through marketing strategies of firms, as the driving forces for innovation and diffusion. It is thus the founder of the enterprise, researchers and technicians or managers who initiate and promote innovative actions accordingly. Brown und Eisenhardt (1995) distinguish innovation process with respect to the solutions proposed by the literature, which they label as rational plan, communication

1 The technology push model become popular in the sixties, which stressed that new scientific inventions and R&D activities were the driving forces for innovation. This model was displaced by the market pull model in the eighties. The implications for management from the latter one are to focus more on market demands, customer needs, etc. and to improve the R&D-marketing link. In the nineties networking and interaction became the dominant elements for the better understanding of innovation processes and their phases which had been separated accordingly. Subsequently, academics and managers stressed that the different phases often ran in parallel. These overlapping phases are sometimes realised by measures of concurrent engineering. Moreover, cooperation with internal and external partners became essential to adopt and convert new ideas promptly.
web or disciplined problem solving paradigm. Accordingly, deliberate planning and action, supporting communication between the involved actors, and the problem-solving of technical, market-related of organisational tasks are the prime approaches to innovation management.

However, the models presented and used by academics, managers or consultants do often not reflect the true nature of the innovation process but are rather idealistic constructs which should help managers and consultants guide their actions. For instance, according to Coopers’ (1987) stage gate model the innovation process is broken up into phases and activities in a sequence form the idea to the market launch. The aim of these and similar models is to reduce complexity and to make the risk of the process manageable. Though, inventors, researchers and managers tend to be over-optimistic about the costs, benefits and market demands and the press delivers dozens of examples of wrong forecast related to new technologies and products. More than often the successes are oversimplified and firms do not always learn from their past failures (Pavitt 2003). These models help to plan and divide tasks and to control the process which is in the end unmanageable in the sense of complexity perspective. Obviously, the presented models are not able to cope with the truly complex and dynamic nature of innovation. Probably, by simplifying the management tasks the “practical methods” miss the mark and are sometimes counterproductive as they harm creativity and variety.

Many empirical studies show that innovations do not follow these simplistic models. Some studies demonstrated, for instance, that the organisation of promoters is not as structured and planned as it might be (Scholl et al. 1993). Moreover, in practice, the various phases cannot be detected, hereby the transition from one stage to next is especially challenging and problematic, e.g. when selection decisions have to be made (Hauschildt 1992).

Thus, some important questions for managing innovation are still not answered sufficiently, as for instance:
1. What is the role of individuals and individual actions?
2. How are promising (cross-functional and complementary) innovation teams set-up?
3. To what extent could the innovation process be divided, planned, and managed by phases?
4. What is the role of random and deliberate actions?

In the last few years the elements for a new innovation model have been presented to overcome the deficiencies described which mostly refer, explicitly or implicitly, to complexity theory. Cunah and Gomes (2003), Dooley and Van de Ven (1999), Cheng and Van de Ven (1996), McKelvey (2003), Anderson (1999), Mitleton-Kelly (1997) and Brown and Eisenhardt (1997) presented the most interesting ones. These models have developed from a linear understanding towards a more network and “complexity” oriented meaning of the innovation process. Although these models are not based systematically on the complexity theory they offer similar explanations for the nature of the innovation process and suggestions for managing innovation.
Complexity-based approaches can deliver some new perspectives and answers for the questions mentioned and will be presented in the next two chapters, starting with a general overview of complexity theory.

**Complexity theory and the CAS model**

No single or commonly agreed complexity theory exists yet. Many concepts, methods and models have been developed and used within the different disciplines. An important theoretical concept is the Complex Adaptive Systems (CAS) model, developed by the complexity researchers Kauffman (1993) and Holland (1995) from the Santa Fe Institute. This model gained attention in many scientific disciplines ranging from biology, physics and computer sciences to economics. CAS can be interpreted as an advancement of evolutionary models which emphasise the concept of self-organisation as additional pillar besides variation and selection. Kauffman (1993) and Holland (1995) criticise the evolutionary models of the eighties since they fail to cope with the spontaneous emergence of order in biological systems. Kauffman (1993) argued that the selection cannot be the only force for evolution and states: „**complexity ... is an alternative source of order ... via natural selection**“. According to Kauffman self-organisation is an inherent property of all living systems.

CAS consist of a large number of agents which can be cells, organisms, populations, organisations, teams or individuals and act according to their local principles or behavioural rules. CAS are characterised by the non-linear interaction between a large number of agents (Holland 1995). Agents are linked to other agents and exchange information and resources. Although these agents follow simple behavioural routines, they show complex patterns of behaviour at the aggregate level. Complex behaviour according to Kauffman is „**... orderly enough to ensure stability, yet full of flexibility and surprise**“. With the notion „**the edge of chaos**“ Kauffman and others state that life emerges on the edge between order and chaos. This edge is the locus of complexity\(^2\). Examples of self-organisation are the bird in a flock. Cillieres (1998, 90) defines self-organisation as: „**The capacity for self-organisation is a property of complex systems which enables them to develop or change internal structures spontaneously and adaptively in order to cope with, or manipulate, their environment.**“

Cilliers (1998) describes some general properties of CAS besides self-organisation and emergence and stresses that the non-linear relations between agents and the existence of feedback loops amplifies the effect of individual behaviour. Finally, CAS are co-evolutionary systems and thus their actions cannot be treated in isolation. Lichtenstein (2000) states that the fact that complex systems are not reducible to their elements and the spontaneous emergence of order are the interesting characteristics relevant for management research.

\(^2\) Kauffman (1995) argues that the life on earth emerged after a critical level of variety in the system consisting of a large number of elements, which he calls supracriticality.
The selection process within CAS is usually modelled by so-called fitness landscapes. Hereby evolution is interpreted as a walk through a landscape with the aim to climb peaks. The higher the peak the higher the fitness of the population. However, depending on topography, e.g. the landscape can be smooth or rugged, populations do not know the optimal path and highest peaks. Based on this idea and the understanding of a system consisting of a large number of agents competing for resources, complexity researchers have developed simulation models in order to study the complex behaviour. Simulations are thus the dominating scientific method of complexity research but still are in infancy for applying it within social sciences.\(^3\)

The question of how this model and the underlying ideas can be adopted for the innovation theory and management will be described in the following.

### Innovation and complexity

Complexity researchers such as Kaufman and Holland even applied the idea of CAS for some questions of economics and business. Kauffman (1995) gives an example of self-organisation on the organisational level when he argues that no single person at IBM knows the world of IBM but nevertheless IBM acts collectively. He also states that the innovation rate of an organisation is related to the question whether the system is supracritical or not, i.e. if diversity is big enough: „New goods and services create niches that call forth the innovations of further new goods and services. ... Diversity begets diversity, driving the growth of complexity“.

Sherman and Schultz (1998) define CAS in the field of business „*A complex adaptive system (a business) is composed of interacting ‘agents’ (employees, managers, board members, customers, suppliers, competitors, and regulations) following rules (blueprints, values, ethics, laws, economics, friendship, profit-maximising), exchanging influence (goods, ideas, money, trust) with their local and global environments (from the cubicle to the global market), and altering the very environment they are responding to by virtue of their ‘simple actions.’“

To describe innovation processes, the concepts of self-organisation and emergence are mostly used by academics. Sherman and Schultz (1998, 23) do not clearly separate between emergence and innovation. They describe emergence as „... the occurrence of properties at any level of development not found at simpler levels, arising out of the depths of complex interactions. “ For them emergence is rather the process of how new combinations are created; innovation is then the outcome of this process. They define self-organisation, by following the notion of Convey and Highfield (1995), as „...the spontaneous emergence of non-equilibrium structural organizations due to collective interactions between a large number of objects“ (Sherman and Schultz 1998, 85). If the management considers the principles of CAS, it can create “emergent novelty”, which can be interpreted as radical innovations.

\(^3\) Genetic algorithms, artificial intelligence and neuronal networks are possible methods for developing simulation models.
Consequently, they argue that radical innovations or emergent novelty will hardly be the result of marketing or customer surveys. These kinds of outcomes are rather of the type of „orthodox novelty“. Dooley (2002, 5020) deals with complexity on the organisational level and defines self-organisation and emergence as follows: „... we refer to a system as self-organizing if it undergoes a process ... whereby new emergent structures, patterns, and properties arise without being externally imposed on the system. Not controlled by a central, hierarchical command-and-control center, self-organization is usually distributed throughout the system“. Emergence is thus the development of new structures, behaviour or processes at a higher level in self-organising systems. For Dooley (2002) the implication of the complexity theory is that organisational behaviour is the result of various events occurring over a long period of time and not the result of few, or one critical, incidents or events. He defines complexity as “the amount of differentiation that exists within different elements constituting the organisation” and is thus roughly equivalent to variety, so Dooley (2002, 5017).

Dooley and Van de Ven (1999) adopt the ideas of complexity researchers when they define innovation as process consisting of cycles of convergent and divergent phases. Whereas in the early stages divergence dominates the process, for instance in the course of the idea creation, during the transformation into tangible products and the market launch convergence is important. They use data from the Minnesota Innovation Research Program (MIRP) and measure the number of activities and their effects, which are then counted on a graph. They interpret deviations between actions and effects as indicator for a divergent phase (Van de Ven et al. 1999). The innovation process is neither chaotic nor random but characterised as divergent and linear in the first stages, and convergent and cyclical in the later stages\(^4\). The empirical data illustrates that innovation is neither the result of a single event nor a spontaneous event but that before innovations occur apparently random actions happened. They found that “... many of these divergent events were not intentionally directed toward starting an innovation” (Dooley and Van de Ven 1999, 17).

Brown and Eisenhardt (1997) studied the innovation processes in the computer industry with its high demand for continuous change and innovation. With their study they contrast the punctuated equilibrium model of change, which assumes that long periods of small, incremental change are interrupted by short periods of radical change, as for instance modelled by Abernathy and Utterback (1978)\(^5\). However, in many industries firms change continuously and alter their products fast. Brown and Eisenhardt’s study is influenced by the complexity theory and the idea that the organisational structures and processes are “... neither so structured that change cannot occur nor so unstructured as chaos ensues”. Based on six case studies they found that successful firms combined limited structure (e.g. with respect to

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\(^4\) Dooley and Van de Ven (1999) argue that his approach is similar to the work of Schumpeter (1911) and Utterbeck (1994), even though their approach is more elaborated.

\(^5\) Similar models have also been proposed for organisational change (e.g. Miller and Friesen 1984, Thusman and Anderson 1986).
responsibility) with extensive interaction and freedom to create improvisation with current projects. They call these structures and processes “semistructure”. This semistructure is a balanced state between order and disorder, so Brown and Eisenhardt.

Cunah and Gomes (2003) adopt findings from the complexity research for a new product development model which they define as improvisational model\(^6\). They argue that innovation processes are characterised by complexity and emergence and that the organisation of innovation processes requires partially disordered processes. Cunah and Gomes (2003) separate five innovation models: the sequential (characterised by a sequence of steps), compression linear (the steps are overlapping), flexible (adaption through diversity and flexibility), integrative (coordination and collaboration amongst all actors involved) and finally the improvisational model. The latter one is proposed by them as the new perspective grounded in the complexity theory. They state: “Improvisation refers to the temporal convergence of planning and execution, which means that an action is improvised when it constitutes a deliberate, real-time response to a problem or opportunity” (Cunah and Gomes 2003, 182). Clear roles, experimentation and gradual convergence are the pillars of the improvisational model with synthesis order and disorder or freedom and control. However, managerial control is executed through the use of minimal structures. These minimal structures may consist of clear roles and responsibilities. However, they do not provide empirical data and examples for illustrating their model in more detail, especially the concept of minimal structure. The challenge for the management is to manage both, efficiency and flexibility and to use disorder productively.

Finally, it is of interest whether simulations based on the CAS model have been used within innovation research. Anderson (1999) and Dooley (1997) are among those authors who call for simulations and describe some elements such models should integrate, though, they do not deliver quantitative models. In general, results of simulation models capturing innovation processes in firms have not been published in the literature so far. However, on the macro level an interesting model has been developed which deals with the question of the development of innovation networks (Gilbert et al. 2001).

\(^6\) Cunah and Gomes (2003) state that the development of product innovation models goes hand in hand with changes in the field of organisational science and that similarities between organisational change and product innovation models are noticeable, which are both influenced by complexity theory.
50 major Austrian innovations: lessons learned from the perspective of complexity theory

Data and method

The findings of the complexity-based perspective on innovation will be analysed empirically based on a study about 50 successful Austrian industrial innovations. This study was carried out between 1997 and 1999 and investigated success factors of the best 50 innovations in different sectors (Leitner 2003). The aim of the study was to identify success factors and specifics of the best Austrian industrial innovations developed in the last 25 years and to illustrate these success stories. Based on a multi-criteria set consisting of factors such as financial return, entrepreneurial achievement, technical solution, economic impact, and newness an expert group selected the 50 best innovations from a list of 600 potential Austrian innovations. These radical product and/or process innovations with a high impact for the company’s development, and sometimes for the entire industrial sector have been developed and launched by industrial firms located in Austria. Thus, innovations of national firms but also of foreign-owned firms with a site in Austria have been studied across all manufacturing sectors ranging from pharmaceuticals to machinery and steel production. Thereby, small as well as large companies have been investigated.

The study combined a quantitative and qualitative approach and gathered data based on a questionnaire as well as information based on semi-structured interviews with firm representatives (inventors, researchers, engineers, entrepreneurs, managing directors) involved in the process. Thereby factors such as the sources of innovation, role of individuals and management, funding of the innovation, marketing, market research, strategy, relevance of co-operations, barriers, and competitive environment were investigated. During the preparation of the case studies, a broad range of factors was analysed. Although some research questions from the classical innovation literature were addressed within the original study (Leitner 2003), specific research questions from the complexity perspective should be addressed in this paper.

For a detailed overview of the innovations and firms studied, selection criteria and the description of the success stories see Leitner (2003).

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7 The study was supported by financial grants of the Austrian Ministry for Economics and Labour.
8 This work is part of a larger research programme of ARC systems research dealing with complexity and innovation.
Conceptual framework

Summarising the findings of the complexity theory, a conceptual framework for analysing the empirical material can be outlined. The characteristics of a complexity-based innovation model are:

- Firms can be understood as complex systems consisting of agents in the form of departments, teams and employees who behave autonomously to some extent. It is the interaction and aggregation of the individual behaviour of agents which makes up the organisation and innovation culture. Thus, the creativity and innovation potential of all agents across the whole organisation has to be recognised.

- In highly dynamic environments self-organisation between different agents is crucial for the innovation process, especially in the fuzzy front end. The configuration of innovation teams, consisting of employees from R&D, production, and sales, is partly a self-organisation process. Self-organisation is an important factor in both, the variation as well as selection phase of innovation and leads to strong teams with the ability to overcome internal organisational barriers. Thereby self-organisation is an order-creating process.

- Innovation is the result of emergent processes. Moreover, new organisational structures, strategies, products and organisational values can also be understood as forms of emergence. Innovation has to be understood as a technological, organisational and social phenomenon.

- To allow self-organisation and emergence to happen, the necessary conditions must exist. Neither too much nor too little structure is fruitful. In this respect, complexity is not the problem but rather the solution of the problem. Innovation is thus a walk on a small path between order and chaos.

In order to study possible relationships and patterns during the new product development process, the behaviour of the various members involved in the innovation process and their interaction has to be analysed considering their manifold interaction patterns and incentives. The empirical data of the 50 Austrian innovations studied contains information about these processes and can thus be interpreted from the complexity perspective.

On the basis of the elements of the complexity-based innovation model, propositions for the truly complex nature of innovation processes can be formulated and will then be discussed based on the empirical findings. Thereby, the focus is on the early stages of the innovation process, often labelled as fuzzy front end.
Results

Proposition 1: Emerging opportunities are important forces for innovation

From the complexity perspective, emerging opportunities on markets or in technological fields can deliver important impulses for innovations. The analysis of the question whether the innovation was planned or rather the result of chance revealed that only in about half the cases innovation was the result of a deliberate search (see table 1). In 10 cases, which are not less than 20% of all studied innovations, the respondent argued that the innovation was more or less the result of chance. This could be a new emerging opportunity on a market, e.g. by an articulation of a demand of a customer, or a new unexpected outcome of research, development and engineering activities. Members of the organisation recognised these suddenly emerging opportunities, which is the truly innovative capability. In the cases where chance played an important role, in 60% the opportunities emerged on markets, in 40% during development activities, e.g. by a discovery. These suddenly emerging opportunities can be interpreted as the discovery of a peak on the walk through the landscape of business opportunities. Thus, it is the exploration of something which already exists. Accordingly, the sensitivity for these opportunities at all levels and departments of the company are important to harvest these opportunities. The question for the impulses for the innovation (see fig. 1) reveals that besides the classical sources, as R&D and Marketing/sales, that competitors, suppliers and the internal production are of significance.

An interesting case is the innovation of an Austrian machinery company, Andritz AG, which developed a new process for the galvanisation of steel. The impulse emerged during talks between the sales manager Josef Hampel and key customers. Moreover, there was no official corporate strategy or goal to develop this new process. Mr. Hampel, also an trained engineer, started to develop the concepts for the new process on his own. Only when he was able to present a well-developed functional concept, an official development team was set up with the aim to construct and build up a pilot system. Three similar examples can be found in the case studies where employees started to develop an idea or innovation without any official order. In all these cases there was no explicit innovation strategy aiming to develop a new product.

Table 1 illustrates the sources of innovations, driving forces and team constitutions for the 50 major Austrian innovations developed and launched between 1975 and 2000.

Tab. 1: Driving factors for innovation in the early stages, Source: Leitner (2003)

<table>
<thead>
<tr>
<th>Impulses for the innovation came from ....</th>
<th>Number of firms*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top management (internal)</td>
<td>16</td>
</tr>
<tr>
<td>R&amp;D (internal)</td>
<td>30</td>
</tr>
<tr>
<td>Production (internal)</td>
<td>6</td>
</tr>
<tr>
<td>Marketing/Sales (internal)</td>
<td>11</td>
</tr>
<tr>
<td>Customers (external)</td>
<td>12</td>
</tr>
<tr>
<td>Competitors (external)</td>
<td>7</td>
</tr>
</tbody>
</table>
Proposition 2: Self-organisation between different members within the organisation and external to the organisation is important

Although self-organisation plays an important role for social life in general, as any sociologist might argue, it is a phenomenon difficult to measure and identify empirically in the organisational context. As defined by academics (see above), self-organisation can be understood as the behaviour of organisational members which is not the result of hierarchical actions and command structures. Self-organisation is a co-ordinated process between various members of an organisation, but could also include the interaction with external actors. In the context of the innovation process, the sudden formation of an innovation team with the aim to develop or put ideas into concrete forms can be regarded as self-organisational process.

In some of the studied 50 radical innovations, self-organisation can be identified and played an important role especially in the early phases of the innovation process. In two third of the cases of the 50 innovations, the core innovation team consisted of at least two members. These members were researchers, technicians, sales managers, entrepreneurs, general managers, etc. The formation of these teams was not always the result of a top-down order, in some cases the teams were rather formed spontaneously, consisting of different members without an official team selection or set-up by a supervisor, director, etc.

The case of the start-up company SEZ semiconductors of Carinthia demonstrated such a process. The company was founded as a spin-off of the newly established semiconductor company AMS in the late eighties. Within AMS Mr. Franz Sumnitsch was responsible for building up parts of the production line and was faced with many problems caused by the
strong Austrian environmental legislation. Thus, he started to develop a new idea for a machinery which should improve the etching process of the wafer production. He had no order from the production director to develop such a new process and thus worked on the idea in his private garage partly in his leisure time. Quickly a team emerged within the company consisting of members of different departments. The good spirit of this team was remarkable and a specific feature and driving force. After a long lasting development process, only partly supported by the top management of AMS, the established team founded a spin-off, in the meanwhile listed at the Zürich Stock Exchange.

In general, the empirical data shows that in 25 cases the management directors were involved in the innovation team, in 23 cases the top management set the strategies and aims for the innovation. Thus, obviously, the interaction of top-down activities– setting up framework conditions and goals - and bottom-up actions – leeway for experimentation and grasping emerging opportunities - are critical factors for the successful management of innovation. This allows self-organisation to happen during the innovation process.

Some of the innovations studied demonstrate that ideas emerged and innovations occurred when top-down and bottom-up initiatives interacted in the proper way. In these cases, the top management set the framework for the corporate development and formulated broad strategies that left a large scope for individual action and the development of the problem solution. In these cases, the members of the organisation had the chance to pick-up and realise opportunities, emerging on the technological dimension or on markets. Here, for instance, the case of the company BWT can be illustrated. BWT is a large Austrian manufacturer of water treatment systems. The company formulated the goal to enter the market for water treatment systems for households. This idea had a large potential because of the general demand for drinking water with less calc, which is a problem especially in Austria. However, the top management did neither define how to solve this problem nor give any specifications, etc. The only task was to recruit rather different employees. One was a young academically trained scientist, the other an engineer with long experience in inventing new systems. It became clear that this team was highly complementary and innovative and was able - during a longer trial- and error period - to develop a new system which led to the development of the new successful product “AQA total”.

**Proposition 3: Innovation is not the result of a single event or single person but the consequence of several factors interacting simultaneously**

Even though individual entrepreneurs and talented inventors planned development programs, targeted research programs and management strategy are important driving forces for successful innovations, the interaction and coincidence of different individuals and events is equally important. Seldom a singular event, which delivers the impulse for an innovation, but

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9 This form of strategy is similar to what Mintzberg and Waters (1985) called umbrella strategy.
rather a set of forces works together simultaneously and creates favourable conditions for innovations. In general, enforced competition, price pressure and new products were important factors that set incentives or triggered off the innovation process. Moreover, newly recruited, often young engineers and researchers delivered unconventional ideas and insights. This sometimes chaotic environment creates a fruitful soil for new ideas and innovations.

In this connection the case of the development of the longest rail worldwide, which is longer than 50 meters, by voestalpine Schienen at the location Donawitz in Styria is of interest. The firm had serious problems in the mid eighties and was hit hard by the crisis of the steel industry\textsuperscript{10}. During this period many strategies, turn-around programmes and ideas for the corporate development and recovery were proposed by the owners, top management and consultants ranging from downsizing, cost cutting to product diversification. However, in the end an idea which emerged from a small group of employees was the rescue for the firm. Three members of the production department had long debates about possible ways to become competitive again. The idea emerged when analysing the real demand and problems of their customers, the railway companies. The solution was to roll 50 meter long rails with a very strong, hardened surface which should at the same be time easier and cheaper to lay. During the development of this idea, some kind of chaotic environment existed in the organisation with no clear vision or committed strategy which allowed to ask unconventional questions, not addressed in that industry in the mid eighties. The small innovation team from the production floor quickly gained the commitment of the new sales manager, who enlarged the core innovation team. Within a few months, the team had finished the research and development work in co-operation with a machinery supplier and the product became a big success finally.

This case again illustrates that the interaction of deliberate managerial actions and emergent phenomena are relevant for successful (radical) innovations. Innovation is not necessarily the output of a single event, a holistic management decision or powerful manager. However, in the context of the complexity-based innovation paradigm, clearly, it is the task of the management to set the framework conditions. Thus, innovation is neither a purely random, nor a serendipity or purely targeted deliberate process\textsuperscript{11}.

With respect to the findings of the limits of planning activities, the question of the role of management instruments becomes evident. Here the success stories studied show that rather simple project management techniques were the most important instruments used. However, the planning of the innovation and its process is difficult: in 60% of the cases studied the time

\textsuperscript{10} All in all, in only 4 cases a corporate crisis existed at the beginning of the innovation.

\textsuperscript{11} Though the process is not as random as decision processes are described by Cohen et al. (1992) who state that strategic decision making is a process of “intermingling … teams, people, decisions, opportunities, ideas and solutions”.
plan for the development had been underestimated\textsuperscript{12}. Time and consequently costs are one of the most difficult factors to manage.

Moreover, at the beginning the estimation of the market demand was troublesome: in about half of all cases the estimation of market demand was false, either too low or too high. In addition, some firms stated that at the beginning they had a rather fuzzy idea of the innovation: 32 firms had a clear idea of the value for the customer and a marketing strategy when starting with the innovation process. However, those representatives interviewed, which developed the innovation in the seventies and early eighties, gave these statements more often. Obviously, the more explicit and professional management of innovation in the eighties and nineties led to comprehensive definitions and valuations of product ideas. This statement though shows the risky character of innovation and the limits of detailed planning at the beginning. Probably too strict rational planning and comprehensive valuation would have led to a decision against the idea or innovation, as some firm representatives argued. It was more than often the belief combined with fascination about the new product idea which enabled and accelerated the process.

Finally, it has to be stated that despite the illustrated empirical evidence of the importance of self-organisation and emergence for successful innovations, in many cases the innovation was the outcome of a deliberate innovation strategy, management programme or targeted research programme. However, even in these cases, on the small scale, e.g. for the solution of specific problems, etc. emergence and self-organisation were important. The separation of tasks and phases of the innovation process, which leads to some kind of standardisation, has thus to be questioned to some extent.

**Conclusion**

Concepts, models and findings of complexity sciences have gained attention within the innovation literature in the last few years in order to explain the development and diffusion of innovations. According to the complexity theory new structures, behaviour, strategy and products emerge in complex systems suddenly and are created between the edge of chaos and order. Accordingly, innovation is neither the result of a single individual event or individual nor a purely chaotic or random event.

The empirical evidence offered in this paper shows the evolutionary character of the innovation process, especially in the early phase where rational planning and strategic management are more than often limited to setting up framework conditions for the general

\textsuperscript{12} Every representative had to tick which of 20 factors listed (costs, time, barriers, market demand, organisational issues, timing, etc.) had been estimated correct, had been overestimated or had been underestimated, comparing the estimation at the beginning of the process and real development after the successful implementation.
direction of the development. Concrete ideas, opportunities and initiatives for innovations often came through the interaction of organisational agents with the coincidence of specific events. The success factors for the 50 major innovations studied are highly firm specific, consisting of a couple of factors. Sector specific factors did not play an important role for the research question addressed in this paper: the phenomena described happened in all industries, in small as well as large companies. For instance, the three characteristics of innovation described occurred in any industry. Moreover, general success patterns were hard to depict. However, it has to be considered that in this paper only radical innovations have been studied, a generalisation for other types of innovations is thus limited.

In general, the 50 innovations studied deliver some evidence that some types or paths of innovative development exist. First, classical, planned top-down innovations where self-organisation and emergence play a role only on the small scale. This type of innovation path could be labelled as “strategically managed”. Secondly, innovations which emerge in a strategic framework set-down by the top management, which, however, let the agents of the organisation relatively great scope of entrepreneurial actions and flexibility. In this framework characterised by top-down and bottom-up action self-organisation and emergence can happen. This innovation path should be labelled as “facilitated emergence”. Thirdly, rather chaotic environments with many internal and external forces interacting enable the formation of innovation teams triggered off by individuals, which could be also described as “purely emergent”.

Summarising the complexity perspective, one can state that three implications can be derived for the nature of the innovation process. Firstly, self-organisation and emergence are important factors within the innovation process, e.g. by the formation of innovation teams within firms. Secondly, the innovation process can be understood as a walk through the landscape of opportunities. Thirdly, innovation emerges on the edge of chaos, neither too much nor too little structure is fruitful and hence improvisation on a narrow path is crucial.

For innovation management the perspective offers new lessons: The complexity perspective of innovation highlights that the framework conditions which enable self-organisation and emergence are crucial. The complexity-based approach stresses that the reduction of complexity by separating stages, planning, forecasting, realising simple organisational structures, etc. has only limited impact or might be contra-productive. Instead, one could argue that complexity has a potential in itself and should be used productively and methods which allow learning and creativity have to be fostered. To enhance the innovative capabilities of an organisation, incentives and frameworks have to be found and set that induce the system to a self-determined development. At the same time this framework should deliver guidance and allow continuity. Then, within this framework self-organisation can happen. Thus, as Baecker (1999) states, complexity is not the problem, but rather the solution
of the problem. Hence, organisations need the right balance between order and disorder, top-down and bottom-up initiatives.

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Literature


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