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VOLUME 17

THE CYCLIC NATURE OF INNOVATION: CONNECTING HARD SCIENCES WITH SOFT VALUES

GUUS BERKHOUT
PATRICK VAN DER DUIN
DAP HARTMANN
ROLAND ORTT

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GUUS BERKHOUT
PATRICK VAN DER DUIN
DAP HARTMANN
ROLAND ORTT

Faculty of Technology, Policy & Management, Delft University of Technology, Delft, The Netherlands

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*Co-authored by David Langley and Nico Pals

**Co-authored by Matthijs Kok
***Co-authored by Maaike C. Kroon

LIST OF CONTRIBUTORS

Authors

Guus Berkhout	Faculty of Technology, Policy & Management, Delft University of Technology, Delft, The Netherlands
Patrick van der Duin	Faculty of Technology, Policy & Management, Delft University of Technology, Delft, The Netherlands
Dap Hartmann	Faculty of Technology, Policy & Management, Delft University of Technology, Delft, The Netherlands
Roland Ortt	Faculty of Technology, Policy & Management, Delft University of Technology, Delft, The Netherlands

Co-Authors

Matthijs Kok	Accenture, Amsterdam, The Netherlands
Maaike Kroon	Faculty of Applied Sciences, Delft University of Technology, Delft, The Netherlands
David Langley	TNO Information and Communication Technology in the Netherlands, Groningen, The Netherlands
Gary D. Libecap	Bren School of Environmental Science and Management, University of California, Santa Barbara, CA, USA, National Bureau of Economic Research, MA, USA, and Hoover Institution, CA, USA
Nico Pals	TNO Information and Communication Technology in the Netherlands, Groningen, The Netherlands

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PROLOGUE

The purpose of innovation is to create new business. In industry, methods and tools are developed on how to organize and manage innovation processes with the objective to better control added-value, risk and cost. Employees, suppliers and customers are principal actors in the process.

In academia, information from observations and case studies is transformed into scientific knowledge with the objective to better understand the successes and failures in innovation and, ultimately, to improve the predictability of the outcome.

Through the years, innovation models have been improved. However, we notice from practice that current models are still too limited to describe the diversity and dynamics of the real innovation world. This observation is confirmed by the fact that the rate of failures in innovation remains high, despite the extensive research in this field.

NEW BUSINESS

Innovation requires change, i.e. change in the way we think and the way we act. These changes may be small or big. Fig. 1 schematically shows our business development view on this matter (Berkhout, 2005).

In life cycle management (right-hand side of Fig. 1), the ambition is to make continuous improvements on existing products and services. Changes are incremental. In this way the life cycle can be extended for many extra years. In industry the typical way of doing this is making use of a company suggestion box: employees on the shop floor are invited to come up with ideas for the improvement of existing solutions. The Japanese are very good in this. They call it *Kaizen*.

In innovation management (left-hand side of Fig. 1), the ambition is to come up with new concepts. This means moving away from existing solutions. As a consequence, innovation shortens the life cycle of existing products and services. Schumpeter calls this property 'creative destruction': life cycle management (LCM) and innovation management (IVM) are in competition with each other. This may cause major dilemmas in business development.

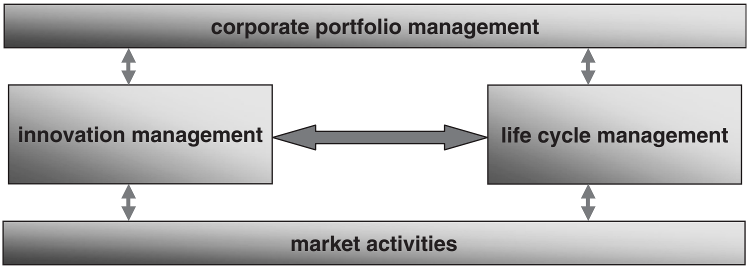

Fig. 1. Business development may be focused on improving existing products and services ('Life Cycle Management') or on designing new products and services ('Innovation Management'). *Note:* A smart business development strategy is to manage a portfolio with a balanced mix of old and new.

Table 1. Innovation Management and Life Cycle Management Require Different Working Environments. They Should not be Mixed in One Organizational Unit.

Innovation Cycle for New Products and Services	Life Cycle for Existing Products and Services
Long-term thinking	Short-term thinking
New solutions	Optimized solutions
Trying to be different	Trying to be lean
Creative power	Operational excellence
Path with many surprises	Path with few surprises
Informal structure	Formal structure
Inspiring leadership	Competent management

It is not always realized that organizations for LCM and IVM require significantly different cultures. This is summarized in Table 1. From the observations in Table 1 it may be concluded that LCM and IVM should not be mixed in one organizational unit. The experience is that a mixed organization is neither one thing nor the other.[1]

INNOVATION DRIVERS

If we look at how innovation is fuelled today, two principally different drivers can be distinguished. One is technological capability and the other is societal needs.

Innovations driven by new technology are of an *exploratory* nature. Curiosity is used to make new scientific discoveries (part of the research process) and creativity is used to generate new imaginative ideas. These discoveries and ideas are combined to new concepts and then prototyped to new technical functions ('products'). Customers have not been identified yet, at least not explicitly. Here, the innovation trajectory is often presented by an 'innovation funnel', showing the process along a time path subdivided into stages and decision points.

Innovations driven by customer needs are of a *backcasting* nature. The specifications of critical and demanding clients are used to give direction to the solving power of a company (or alliance of companies for that matter). Here, the innovation process is often presented by an 'innovation roadmap', showing step by step what needs be achieved to arrive at a solution that meets user specifications.

In the real world, we can observe many different combinations of technological capabilities and societal needs that drive the innovation process. This dual aspect of the forces behind innovation is the topic of this volume. Using an iterative process of *forward-extrapolating* emerging capabilities and *backward-extrapolating* emerging needs, product-service can be constructed that influence the strategic decisions how to proceed. In many industrial sectors, we notice that the innovation culture is still technology-push.

MANAGEMENT OF CHANGE

If we look at how processes of change are managed today, two principally different styles can be distinguished. The first one is top-down strategic planning and the second one is bottom-up adaptive learning (Ortt & Smits, 2006).

Projects being managed according to a strategic plan are regularly judged by a committee of experts. Project continuation and resource allocation are decided by this committee. Minimizing risk is an important issue in this approach. This is the environment of incremental change as we see in LCM.

Projects managed by the self-organizing principle show that the responsibility for success is delegated to the project teams. Feedback from success and failure causes continuous adaptations along the innovation path. These adaptations facilitate a learning process in the teams. Maximizing opportunity is an important issue in this approach. This is the environment of radical change as we see in IVM.

In the real world, a wide variety of combinations of centralized strategic planning and decentralized adaptive learning can be found in innovation management. This means that some compromise between minimizing risk and maximizing opportunity is looked for. In the foregoing we have argued that such a compromise is not a good choice for a single organizational unit: the shop floor shows neither creative power nor operational excellence. It is, however, a good strategy for business development at corporate level. By forming a dynamic portfolio with leads, prospects, early and mature products, a balanced mix can be created depending on strategic criteria with respect to short-term profitability and long-term continuity.

Dynamic portfolio management is beyond the scope of this book. We will concentrate on improving innovation management by giving new insight in how innovation systems (should) operate.

DELPHI CONSORTIUM

As mentioned earlier, the purpose of innovation is to develop new business. In this volume, the environment for new business is represented at three levels of abstraction: (1) the framework for new business, (2) the cyclic innovation model and (3) the open technological infrastructure. The hierarchy 'business–innovation–technology' is considered to be an important feature. It emphasizes that technological research is part of the innovation model, and that the innovation model is again part of the framework for new business.

This multi-level concept for new business creation was developed in the last two decades by a long-lasting industry–university collaboration. In 1983, the first author founded a geophysical research consortium, the Delphi consortium,[2] at the Delft University of Technology (TU Delft) in the Netherlands. The mission of the consortium was, and still is, to develop new imaging technology for the geo-energy sector. This technology collects with the aid of sound (seismic waves) detailed geological information from below the surface of the earth, typically up to 10 km of depth. This geological information is vital for the industry. Not only in the search for new oil and gas accumulations, but also in monitoring the exploitation of existing reservoirs. The importance of seismic imaging technology is still increasing because, nowadays, the easy-to-detect reservoirs have been found already. The difficult ones are left. In 1982, the consortium started with five contributing companies and today the consortium has grown to thirty members. They not only include all major companies such as Shell and BP, but also a large variety of innovative service companies from all continents. This means that most parts of the entire upstream value chain are represented in the consortium.

The biggest challenge has been to keep the existing members in the consortium as well as to attract new companies. Through the years it became clear that, to stay successful, the Delphi imaging technology should evolve into new technical capability that would outperform the existing generation of commercially available products and services. In addition, it became clear that this new capability should generate new business that would make the consortium fee for the Delphi members an attractive investment. This means that it was not only necessary to be successful as a professor of Geophysics (developing with my team promising geophysical technology). It was also necessary to understand the bottlenecks and opportunities in the industry, now and in the future. And it was also necessary to know whether and how the Delphi technology was transformed by the consortium members via new products and services into new business. All experience from that extensive journey of 25 years have been made explicit and the result can be found in the theoretical framework that is described in part I of this volume. We are now translating all this knowledge to a growing number of business areas outside the geophysical community, where it all started.

CONTENTS OF THIS VOLUME

We have subdivided the contents into three parts:

I. Theoretical framework
II. Interaction with related scientific areas
III. New business applications

In the Epilogue, the authors summarize on what has been achieved so far and what is next on the research program.

I. *Theoretical Framework*

The first three chapters contain the theoretical background. Chapter 1 summarizes the rich history of innovation models. In Chapter 2 the total framework is explained, showing the advantages of the multi-level concept and the importance of feedback. Chapter 3 attaches the names of prominent entrepreneurial scientists to the cycles of the process model with the objective to increase the understanding of the model.

II. *Interaction with Related Scientific Areas*

The next three chapters describe scientific areas that are closely related to innovation and new business. Chapter 4 discusses how futures research can be improved by multi-mode foresighting, making use of the cyclic interaction between those nodes. In Chapter 5 it is argued that market research should be enriched by the social sciences cycle of the process model. Emerging and receding markets should not only be observed, those transitions should also be understood. Chapter 6 provides new insight in intellectual property by making a new subdivision according to the cycles of the process model.

III. *New Business Applications*

The last three chapters illustrate the link between technology, innovation and new business in the sectors of telecommunication, new materials and green chemistry. Chapter 7 shows how in the telecom industry the combination of a well-documented transition path with the cyclic process model helps to understand the contribution of an innovation project in the total path of change. In Chapter 8, the cyclic process model is used to select and position partners for the set up of a new business in the field of Thixomolding®. Chapter 9 describes a strategy how to develop for multi-value innovation in the chemical industry by using a revolutionary technological process.

NOTES

1. It is appropriate to quote Nicholas Negroponte (MIT) here: "gradual growth is the worst enemy of innovation".
2. http://www.delphi.tudelft.nl

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Some of the chapters in this volume are co-authored by a number of our colleagues. Chapter 5 with David Langley and Nico Pals of TNO Information and Communication Technology in the Netherlands. Chapter 8 was a collaboration with Matthijs Kok of Accenture and Chapter 9 was co-authored by Maaike Kroon of TU Delft. We greatly appreciate the very valuable contributions of all our co-authors.

INTRODUCTION

Gary D. Libecap

Sustained modern economic growth is less than 300 years old. Most of the human experience has been a Malthusian one – brief periods of relative plenty for some, followed by collapse due to famine, drought, or other exogenous factors, or due to internal factors such as war or excessive population growth that outstripped the resource base. In all cases, general productivity growth was short term and minimal and each society's well-being was tied inexorably to the condition and stock of natural resources.

Something changed, however, in the eighteenth century in Britian and northwestern Europe – perhaps an unlikely area given that previous brief flowerings of civilization and economic growth had occurred elsewhere – in China, along the Indus Valley of India, and in the Middle East. Yet, economic progress began not in those areas, but in Europe. It broke the link to resource endownments and brought unimaginable levels of per capita economic well-being. Many of the early sources of productivity growth began in agriculture and transportation, but they spread to textiles and energy sources. Gradually, the industrial revolution began. Factories developed; new products and processes were created; markets expanded; and the human condition vastly improved. Mortality dropped; life expectancy increased; populations grew; cities emerged; education and health care advanced; culture – elite and mass expanded; and eventually, environmental quality improved. Modern developed societies appeared.

Today, for populations in the developed world, there is very little that seems similar to what their remote ancestors experienced. And beginning in the latter part of the twentieth century, the process of economic

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development again lurched forward with rapid increases in economic growth in southeast Asia, China, and India. This has brought higher levels of economic well-being to more of the world's population than has ever been experienced. In developed areas, new opportunities for human advancement seem endless, and there are the means to address lingering problems of health care, education, and environmental stress. Nevertheless, some areas of the world that grew earlier have lagged – Latin America is a notable example, and other parts, especially in Africa, have had limited successful economic growth at any time. Indeed, the inhabitants of many parts of Africa have more in common with their remote ancestors than with the populations of Europe or North America.

The economic growth following the Industrial Revolution in Europe, the remarkable expansion in parts of Asia today, and the less positive experience of parts of Africa and Latin America direct attention to the sources of economic progress. Why did the Industrial Revolution take place in Europe in the eighteenth century? What are the sources of economic advancement today? And why does economic development spread to some areas and not to others?

A key component to the answer to all of these questions is technological change. Technological change raises productivity and allows societies to go beyond the constraints imposed by their resource bases. So, what is the source of technological change? What promotes it? What hinders it? What institutions are required? How does it take place? These are of course, the big questions, and they have been addressed in a macro sense by many, including David Landes (1982) in *The Unbound Prometheus: Technological Change and Industrial Development in Western Europe from 1750 to the Present*, Joel Mokyr (1990) in *The Lever of Riches: Technological Creativity and Economic Progress*, Kenneth Pomeranz (2000) in *The Great Diverrgence: China, Europe, and the Making of the Modern World Economy*. More micro-oriented studies of research and development and technological change at the organizational level are by Nathan Rosenberg (1982) in *Exploring the Black Box: Technology and Economics*, David Mowery and Richard Nelson (1999) in *The Sources of Industrial Leadership* and many others. Recently, the importance of entrepreneurship has been emphasized by Carl Schramm (2006) in *The Entrepreneurial Imperative*.

Despite all of this effort, technological change, productivity growth, the contribution of basic university and govenment research, and of more applied research and development within private firms remain critical issues to be examined in more detail. This is where this volume, *New Insights in Innovation* by Berkhout, Van der Duin, Ortt, and Hartmann, fits in. These authors, all from the Delft University of Technology in the Netherlands, provide 9 chapters on the use of the Cyclic Innovation Model (CIM). Basically, this model views technological change and innovation as complex interactive outcomes of research in basic and applied science, leadership, and market information feedbacks. Real problems are encountered; research addresses them; processes, products, and organizational structures are launched; consumers and other users respond; new research takes place; modifications are provided; new technologies and innovations are offered. This circular process involves many different collaborations and requires the constant inflow of new information. As pointed out in the volume, some organizational structures are better adapted to the interaction and feedback necessarily required for modern technological change than are others. Both theoretical arguments and case studies of mobile telecommunications, magnesium thixomolding, and chemical and pharmaceutical production processes are provided to illustrate the components of the CIM model of innovation.

By emphasizing the circular, interactive process of innovation, the authors provide a valuable contribution to our knowledge of how technological progress occurs and the organization arrangments, intellectual property protections, and overall incentives for risk-taking necessary to sustain it. An outline of the volume is provided in the Prologue that follows.

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PART I:
THEORETICAL FRAMEWORK

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CHAPTER 1

INNOVATION IN A HISTORICAL PERSPECTIVE

ABSTRACT

In order to understand today's innovation models, we need to look at the historical development of these models. This chapter describes the succession of the R&D management generations and discusses the innovation models in each generation (Section 2). The shortcomings of these models and the requirements for improved versions are summarized in Section 3. In Section 4, we will explain why new models of innovation should be circular and multi-layered.

1. INTRODUCTION

This chapter takes a historical perspective on innovation. Different generations of innovation models will be compared, and requirements for new models will be discussed.

1.1. Innovation as Science or Craftsmanship

From the beginning of mankind on, humans have created innovations. Before the nineteenth century, in many cases scientific findings,

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breakthrough technologies and revolutionary new products resulted from the painstaking efforts of inventive individuals rather than from coordinated innovation activities in large organizations. Some of these individuals were scientists, like Huijgens, the Dutch mathematician, astronomer and physicist who founded the wave theory of light in the seventeenth century. Other individuals were anonymous craftsman like those who developed and improved windmills during the Middle-Ages.

There was hardly any cross-fertilization or cooperation between scientists and craftsmen. An illustration of the lack of relationship between science and engineering can be witnessed in the early days of radio research. Maxwell, a scientist, in 1864 described the principle of radio in theory, Hertz proved the principle in an experimental setting in 1888. Although these scientific contributions can be considered very important, the result was hardly useable in practice. Marconi, an engineer, systematically started to experiment with different types of antennas and radio systems, and thereby managed to build a practical radio communication system that could be used over long distances (Encyclopedia Brittannica, 2004). Scientists did not cooperate to transfer their knowledge to engineers like Marconi. On the contrary, they even seem to have disdained the efforts of the engineers a bit.

In some cases, for example in shipbuilding, a more or less systematic effort to improve products can be witnessed even in the seventeenth century (Encyclopedia Brittannica, 2004). Shipbuilding yards in this century were relatively large organizations with a structure that resembled a modern project-based organization. Their innovation efforts seem to herald an innovation approach that would be more widely adopted about three centuries later.

1.2. The Rise of Research & Development (R&D)

At the end of the nineteenth century, systematic innovation activities in large corporations were started. Innovation became Research & Development (R&D). Large companies witnessed a gap between the scientific findings from universities and their innovation requirements. Whereas universities strived for revolutionary new knowledge, companies strived for revolutionary new applications of knowledge in their products and services. From the perspective of a company, innovation should be deliberately aimed at achieving business goals. By the end of the 1870s, the first industrial research laboratories were organized in Germany by synthetic dye manufacturers, who realized that science can create patentable inventions that, in turn, yield new and improved products. In the first decade of the twentieth century, industrial research laboratories were also organized in the US by General Electric and DuPont (Basala, 2001).

During the twentieth century, different approaches of how to manage R&D can be distinguished. These so-called R&D management generations will be discussed in the next section. The first, second and third generations are based on the idea that R&D is basically performed within a company. The innovation process during these R&D management generations is represented by an essentially linear process. The origin of this type of process lies in the fact that innovation is seen as a particular type of project that can be planned upfront in subsequent phases.

1.3. The Rise of the Systems Approach

Three developments during the late twentieth century make this linear approach outdated (Smits & Kuhlman, 2004). First, the increased uncertainty in the market and technology demands an innovation approach that enables learning by doing rather than planning up-front (Lynn, Morone, & Paulson, 1996). Learning by doing requires a process that not only enables iterations between steps but also requires various mechanisms of feedback, and feed forward between the separate processes of change like scientific explorations and technological research. The combination of these subprocesses will result in something significantly more complex than a single linear innovation process. Second, in the latest R&D management generations, innovation processes are managed in networks of organizations. Instead of the closed innovation paradigm in which companies develop innovations on their own, an open innovation paradigm emerges in which organizations cooperate with partners, and sell and buy innovation components or subresults in different phases of the process (Chesbrough, 2003). Tuning the processes from different organizations will be much more complex than managing a simple, linear model in a single organization. Third, innovation processes are influenced by actors and factors on different levels of aggregation. Innovation can be studied on the level of a nation, an industry, an organization or on the level of a project (Freeman, 1997).

These developments require a system perspective. The system approach deserves more attention because it can describe the interlinked activities of scientific explorations, technological research, product creation and market transitions. Innovation occurs in the context of a so-called innovation system (Freeman & Lundvall, 1988; Nelson, 1993; Lundvall, 1992; Barré, Gibbons, Maddox, Martin, & Papon, 1997). A system perspective makes sense for various reasons. First, the successful market introduction of an innovation often depends on the adoption of new organizational practices (in terms of marketing, manufacturing, and so on), the availability of complementary products and services, infrastructural (re-)arrangements, and so on. Second, firms cannot innovate successfully without institutions (rules and standards), qualified people, an adequate infrastructure and a high level and tuned knowledge infrastructure.

2. THE R&D MANAGEMENT GENERATIONS IN MORE DETAIL

Table 1.1 provides an overview of four generations of R&D management on the basis of various sources (Liayanage, Greenfield, & Don, 1999; Miller, 2001; Niosi, 1999; Rothwell, 1994; Roussel, Saad, & Erickson, 1991). The first column shows the period in which a specific generation is thought to prevail. The second column describes the philosophy and main characteristics of each generation as well as their main disadvantages. The last column briefly mentions the structure of the innovation process that prevailed during each generation (Chiesa, 2001).

2.1. The First Generation of R&D Management

The first generation of R&D management considers scientific discovery as the starting point of innovation processes. At that time, universities are thought to be the primary source of scientific discovery. As a result, R&D organizations are structured like universities. Departments in R&D institutes are essentially mono-disciplinary. In general, the structure of innovation processes is linear sequential and of a technology-push nature (Fig. 1.1). During the process, different departments subsequently contribute to the innovation. This type of process has yielded numerous breakthrough technologies such as the laser, nuclear power plants and DNA 'finger prints'.

This first generation of R&D management has significant disadvantages. The final responsibility for the innovation is not always clear if it moves from department to department because a project management approach is not yet adopted. The lack of a project approach also implies that little attention is paid to the overall transformation process from idea to innovation. Scientific freedom of professionals seems more important than relevance (in terms of commercial results) for the company. Innovation does not always have

Table 1.1. Short Description of Four Generations of R&D Management.

Period of the R&D Management Generations	Description of the Generations	Structure of the Innovation Processes
1st generation (1950s–mid-1960s)	*Technology (science) push* The process of commercialization of technological change, i.e., the industrial innovation process, was generally perceived as a linear progression from scientific discovery, through technological developments in firms, to the marketplace. Because science is considered the starting point, R&D-institutes are structured like scientific institutions *Disadvantages* • Little attention is paid to the transformation process itself, or the role of the market place • Scientific freedom is considered more important than the relevance and accountability of the research itself • Innovation projects have no strategic goals, maybe short-term goals on the level of the project. There is no direct relationship with general management • Commercial aspects are incorporated quite late in the innovation process. • Responsibility for the research is handed over from manager to manager (no project leader is appointed) and, therefore, final responsibility is not clear • Professional project management practices are not applied	Linear sequential process from department to department, starting with scientific discovery

Table 1.1. (*Continued*)

Period of the R&D Management Generations	Description of the Generations	Structure of the Innovation Processes
2nd generation (mid-960s–early 1970s).	*Market pull* (*need-pull*) The market role is the source of innovations and the R&D organization merely has a reactive role. Because innovation processes are managed as projects, R&D-institutes are organized in a matrix *Disadvantages* • Neglects long-term R&D programs and, therefore, leads to "incrementalism" only • Projects are individual units, strategic relationships between these projects and corporate goals were not yet established. It was impossible to serve company goals that superseded the interests of separate internal clients	Linear sequential process in a project, starting with market need
3rd generation (early 1970s–mid 1980s)	*Market pull and technology push combined* Innovation is a process that, at each stage, enables interaction between technological capabilities and market needs. This interaction is generally facilitated by intra- and extra-organizational communication networks. These networks link R&D to in-house functions and link the firm to scientific and technological communities as well as to the marketplace. Innovation projects are considered to be part of a portfolio of projects. The goals of this portfolio are aligned with the corporate strategy *Disadvantages* • Focuses on product and process innovations rather than market and organizational innovations	Model of an essentially sequential process with feedback loops and interaction with market needs and state of the art technology at each stage

Table 1.1. (*Continued*)

Period of the R&D Management Generations	Description of the Generations	Structure of the Innovation Processes
	• Focuses on the creation of innovations rather than the exploitation • Focuses on evolutionary improvements rather than breakthroughs	
4th generation (mid-1980s–early 2000s)	*R&D in alliances; Parallel and Integrated R&D, from R&D to new business development* (*NBD*) R&D departments belong to a network of internal departments and external organizations. R&D management means managing research links, networks and external research environments. Because of the number of actors involved, development processes are scheduled in parallel. Parallel development can significantly increase product development speed. The 4th generation is broader than the 3rd since it includes business and market models that encompass the management of knowledge, technology and market/industry infrastructure *Future possibilities for improvement* • Increased networking and integration with internal and external partners • Increased use of information technology to cooperate and communicate • Increased flexibility of the structure of innovation processes	Coordinated process of innovation in a network of partners. The required coordination is often attained by system integration (with key suppliers and customers) and parallel development (of components or modules of the innovation)

Note: The description is based on Liayanage and Greenfield (1999), Miller (2001), Niosi (1999), Rothwell (1994) and Roussel et al. (1991).

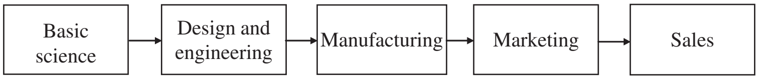

Fig. 1.1. The structure of a first generation innovation processes.

strategic goals and there is hardly a relationship between researchers and general management. Market needs and commercial aspects are incorporated late into the process. As a result, failures because of a lack of market need are discovered quite late. During the first generation of R&D management, much effort is put into developing unsuccessful innovations.

2.2. The Second Generation of R&D Management

During the second generation of R&D management, it is recognized that market aspects should be considered earlier in the process. In fact, the market is now regarded as the main source of new ideas. Consumer research becomes the basis for new product ideas (Fornell & Menko, 1981). Innovation processes are often managed like multi-disciplinary projects in which R&D and marketing personnel collaborated. In large companies, R&D projects are often performed for internal company clients. A project leader, rather than subsequent managers of departments, has the final responsibility for the overall transformation process. Along with multi-disciplinary projects, many R&D institutes adopt a matrix organizational structure. The structure of the innovation process remains essentially linear sequential, but of a market-pull nature (Fig. 1.2).

The approach of the second generation of R&D management leads to new disadvantages such as a focus on small improvements of existing products. The main reason for this focus is that potential consumers can hardly express any need beyond the needs solved by familiar products (Bennett & Cooper, 1982; Tauber, 1974). After the second generation of R&D, the increased influence of marketing in product development is severely criticized since it neglects the long-term R&D programs aimed at developing the future technological assets of a company (Bennett & Cooper, 1982). Another drawback of the second generation is that the innovation projects are treated separately. As each project serves the goals of different internal company clients, strategic relationships

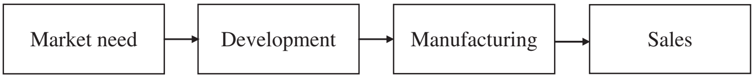

Fig. 1.2. The structure of a second generation innovation processes.

amongst the innovation projects are not established. Relationships between the projects and the strategic goals of company are not established either.

2.3. The Third Generation of R&D Management

The third generation of R&D management combines the market-pull and technology-push approaches. Projects are combined in programs that, in turn, are directly related to strategic company goals. The structure of innovation processes remains essentially linear, but with feedback loops and constant interaction with market and technological factors. Companies try to find partners with essential technological and market knowledge. Because of this interaction, communication networks are formed with these partners (Fig. 1.3).

The main disadvantage of the third generation is a focus on product and process innovations (Miller, 2001). The exploitation of product and process innovations in many cases also requires organizational and market innovations. When a manufacturer, for example, is used to produce a limited number of product variants but after a change in strategy enables customers to order semi-custom built products, he not only has to change his products and production processes, but he must also change the interaction with his customers and the way in which the production process is planned. The necessary changes in work processes will inevitably bear on the organizational structure. Traditionally, R&D labs have no experience with organizational and market renewal, which used to be the domains of top managers and marketers. Involvement of top managers with R&D and close links between innovation processes and strategic company goals, facilitate the transfer of innovations and knowledge from the R&D labs to the parent company. The transfer of innovations from the company to the market, however, is hampered by a limited experience of the R&D departments with market and organizational renewal. In summary, a disadvantage of the third generation is its focus on initiating innovations rather than exploiting them.

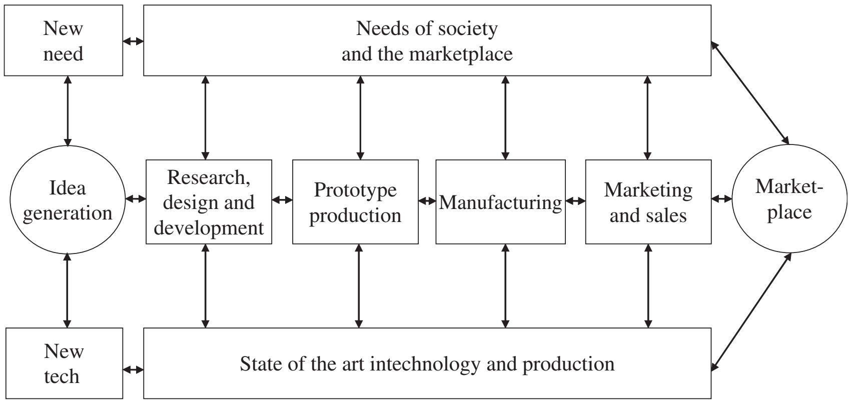

Fig. 1.3. The structure of a third generation innovation processes.

2.4. The Fourth Generation of R&D Management

During the fourth generation of R&D management, innovation projects are no longer carried out in the isolation of R&D departments, but are carried out in large networks with internal partners (other company departments) and with external partners (universities, suppliers, customers, etc.). More specifically, the degree of integration of innovating companies with their suppliers and customers increases. New products are developed more quickly and more frequently because of parallel innovation processes. Exploitation has always been a bottleneck of R&D. The fourth generation pays more attention to the market and the organizational innovations required to successfully introduce product innovations. The term innovation broadens out from product innovation to process-, organization- and market-innovation (Trott, 2002). The traditional R&D department gradually incorporates the new business development department of a company. A single type of innovation process representing this generation of R&D management practices can hardly be distinguished.

A disadvantage of the fourth generation of R&D management is the complexity of R&D in general, and the innovation processes in particular. To handle this complexity, more flexible organizations and the application of information technology are proposed. Some authors describe a fifth generation of R&D from the early 1990s on (Rothwell, 1994). We believe that this ‘fifth generation’ is merely an implementation of the fourth generation, a view that Rothwell appears to share. “The development of 5G is essentially a development of the 4G (parallel, integrated) process […]" (Rothwell, 1994).

In summary, Table 1.1 shows that R&D management has changed significantly in five decades. Organizational structures of R&D departments evolved from a functional structure to a matrix structure, and finally to more advanced network structures. Each R&D management generation is characterized by an innovation process with its particular disadvantages. New generations are figured out to overcome the disadvantages of a previous generation but inevitably lead to new disadvantages.

So far, the description focused on internal considerations, i.e., how to overcome disadvantages of subsequent R&D management practices. From the 1950s on, conditions in the external environment of innovating organizations have increased the pressure on R&D management in general and on the management of innovation processes in particular. It is important to notice the main changes in the external conditions since these provide additional explanations for the changes in these practices (for a full discussion of these conditions see van der Duin, Ortt, Hartmann, & Berkhout, 2006 and Ortt & Smits, 2006). In short, some of the main changes in the external conditions are:

- Competition has increased in many markets. Liberalization of markets and globalization enormously increases the number of potential competitors, many of which try to develop and introduce innovations and thereby increase the pressure on innovation processes in separate companies.
- Technologies that are required to develop new products have evolved. The number of technologies that have to be mastered to produce a mobile phone, for example, has increased considerably (Tidd, Bessant, & Pavitt, 2001). Therefore, technological competences to develop new products have become too complex to be mastered by a single company.
- Globalization forces companies to focus on core competences. As a result, some of the competences required to innovate are no longer available in a single firm (Prahalad & Hamel, 1994). The alliances that are needed to innovate require increased coordination and introduce new risks. Alliances are often aimed at increasing development speed, and decreasing the cost and risk of development. But these alliances also demand additional management attention (Tidd et al., 2001).
- The kind of innovations that R&D should provide broadened out to comprise of new products, as well as the new production and distribution processes, organizational and market renewal that come along with these

new products. Formerly distinct activities like new business development, new product development, market development and development of new organizational structures should be coordinated to form a consistent picture (Trott, 2002).

- New sustaining technologies, like computing and communication technologies, enable a more advanced and efficient management of the design, manufacturing, marketing and distribution processes with regard to innovations (Miller, 2001). Yet, incorporating these technologies in R&D processes and fully exploit their potential implies that R&D functions and the parent companies have to renew their own organization.
- Customers are generally more demanding with regard to products. Products have to be personalized, of high quality, easily understandable, yet with all possible features. Moreover, companies are held liable for the consequences of their products. An increased government and public scrutiny of business decisions in ethical, social and environmental issues can be noticed (Gupta & Wilemon, 1996; Wind & Mahajan, 1997).

The result of the combination of the efforts to improve the practice of innovation and the external pressures on innovation are that R&D management in general, and innovation processes in particular have become increasingly complex. In the successive generations, new activities are added to (rather than removed from) the innovation process and new linkages between actors are added to (rather than removed from) innovation processes.

The increasing complexity of innovation processes is shortly summarized.

- The organization of innovation changes from a process in which an innovation is handed over from department to department (the first generation) into a multi-disciplinary project process (later generations). During the third generation, innovation projects become organized in programs that are directly related to the company strategy. In the fourth generation, innovations are organized in networks of external and internal partners.
- ‘Technology push’ and ‘market pull’ approaches from the first and second generation are combined in later generations because market and technological aspects are considered to be important throughout the innovation process. Technology and market factors are sometimes depicted as two levels, along a sequential process of innovation.

- Feedback loops are introduced in innovation processes. Like many complex and multi-phase processes, new findings during an innovation process sometimes imply that previous steps must be re-evaluated.
- Activities in innovation processes are organized more in parallel to increase the speed of development.

3. THE PROBLEMS WITH FOURTH GENERATION MODELS REQUIRE A FRESH APPROACH

This section will discuss some of the problems in recent models of innovation management. The success rate of innovation processes has remained low over the last decades. Crawford (1979) estimated that during the 1970s, one-third of the new products that were introduced in the market become a success. Similar results are found by Booz, Allen, and Hamilton (1982). It is remarkable that this success rate has not increased significantly in the last decades (Crawford, 1987, 1977; Wind & Mahajan, 1997). On the one hand, it can be stated that the environment of innovation processes has become much more complex so attaining the same success rate as 30 years ago may require a lot of improvement. On the other hand, problems with recent models of innovation may hamper an increase of this success rate. These problems are reflected in the fact that many companies lag behind in their innovation practice. Many companies still apply intuitive and informal ways to innovate (Griffin, 1997; Nessim, Ayers, Ridnour, & Gordon, 1995). Different innovation practices are reported *across* companies (Griffin, 1997). Empirical research shows that in the 1990s many companies adopted advanced methods of R&D management, although at the same time a remarkably large percentage of firms did not apply any formal procedures with regard to product development (Griffin, 1997; Nessim et al., 1995). Such innovation practices are considered predating even the first generation of R&D management.

3.1. An Integrated Model Is Lacking

So far, incremental changes in the model of innovation management are implemented. Sometimes, solutions for specific changes in the environment are provided separately, such as suggestions on how to increase development speed in order to cope with the decreasing product life cycles (Cordero, 1991; Rothwell, 1994; Kessler & Chakrabarti, 1999; Smith, 1999), or suggestions on how to make products that fulfill the needs and wants of customers (Greenhalgh, 1985). An integrated model, however, is lacking.

3.2. Current Models Diverge Considerably from the Actual Practice of Successful Firms

Different innovation practices are adopted *within* successful companies. From 1990 to 1995, the percentage of US firms using multiple product development structures increased from 53 to 62% (Page, 1993). Apparently, the idea of one mainstream model does no longer reflect the actual practice of companies that deliberately adopt multiple approaches.

3.3. Current Models Lack the Flexibility to Adapt to the Context

Many companies believe that different kinds of processes are appropriate in different situations. Empirical results prove that different practices yield the best performance in different situations (Griffin, 1997; Miller & Blais, 1993; Nessim et al., 1995). The best companies do not succeed by using just one product development practice more extensively or better, but by simultaneously using a number of different practices more effectively (Griffin, 1997). The recent models of innovation management lack the flexibility to adapt to different situations.

3.4. Current Models Focus on Technology Product Combinations

In innovation management the focus has been on designing new products. In the previous section, it is described that the kinds of innovations that R&D should provide have broadened out to comprise of new products, as well as the new production and distribution processes, organizational and market renewal that come along with these new products. The third generation models state that market and technology information should be applied throughout the entire innovation process, but these models still focus on one type of innovation.

3.5. Current Models Focus on Creating Innovations Rather Than Exploiting Them

Many companies suffer from a very valuable yet unused pile of innovations. Innovation models have focused on creating innovations but forgot to describe how the resulting innovations can be successfully exploited in the market. Chesbrough (2003) suggests creating a preliminary business model and testing it together with the product concept to increase the chances that an innovation can be successfully exploited once it is developed. The *open innovation* approach also means that already *during* the innovation process subresults of this process can be sold or bought (for example by licensing in or licensing out). So, even before the market introduction of an innovation, exploitation of the result is possible.

3.6. Current Models Are Essentially Linear

A linear sequential innovation model that just incorporates technology and market information throughout a product innovation process does no longer suffice to describe the iterative and very flexible processes that are required in uncertain circumstances. Lynn et al. (1996) describe such a process, referred to as probe and learn, in which product concepts are introduced in the market, improved on the basis of the first market results, re-introduced, and so on.

3.7. Current Models Focus on the Level of the Innovation Project and the R&D Organization

Innovation can be described at different levels of aggregation like the project, organization and industry or country level. On the project level, the focus is on a singular innovation process, its staffing, structure, procedures, and so on. On the organization level, the focus is on the position of innovation in an organization. On the industry level, the focus is on the network of organizations in an industry. On the country level, the focus is on the all sustaining and stimulating facilities, like the regulation and legislation, the availability of education facilities and the existence of complementary partners that foster innovation in general and across industries. In general, innovation management models focus on the project and organization level of innovation. However, the previous section clearly indicated that multiple partners from different organizations nowadays cooperate to innovate. In order to describe and analyze these patterns of cooperation, a higher level perspective should be chosen. A system perspective can be adopted to form models of innovation that describe multiple subprocesses of renewal.

4. A NEW DIRECTION IN MODELING INNOVATION: CIRCULAR AND MULTI-LAYERED

New models of innovation are required to cope with the issues in the previous section. In this book, we take the stance that the purpose of innovation is to create *new business* and that an important enabler of innovation is *new technology*. As a consequence, innovation systems function as an interface between new technology and new business. Together they form a multi-layer environment that describes the wide variety of activities on three interconnected layers. These layers imply that innovation is more than technology, and business is more than innovation.

In addition, the involved processes in innovation are not positioned in a chain: together they form a 'circle of change'. Like in a circle, there is no fixed beginning or end. To put it differently: Each of the positions can turn out to be the beginning in specific cases of innovation. In some cases, market transitions turn out to be the starting-point, other cases start with a scientific discovery. Moreover, the circle may be completed multiple times and thereby reflects the iterative nature of many innovation processes. The approach to connect different processes of change reveals new types of interactions such as the interaction between the soft sciences and engineering issues or the interaction between the hard sciences and social values.

We will show that this new way of positioning – circular and multi-layered – not only enables a better understanding and explanation of the processes that we observe in practice (why they succeed or fail), but also provides new ways to govern and to influence those processes.

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CHAPTER 2

CONNECTING TECHNICAL CAPABILITIES WITH SOCIETAL NEEDS: THE POWER OF CYCLIC INTERACTION

ABSTRACT

Innovation models should give insight into the success and failure of generating new business. Considering the high degree of complexity, it is proposed to view such models at different levels of abstraction. It is also proposed to make feedback an essential property of the process model. The result of this line of thinking is an integrated environment for the creation of new business. In this multi-layer environment, innovation is positioned as the interconnecting activity between the development of new technology and business, and the involved process model is represented by a circle of change.

1. INTRODUCTION

In former times, economies were largely based on the traditional production of goods, using the two factors of production: capital and labor. Industrialization and globalization have brought about growing competition,

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forcing companies to produce goods with higher performance and at lower cost. This started the *knowledge economy*, in which smarter tools and machines expanded possibilities; formal knowledge became the third factor of production.[1] Workflows were designed more intelligently, and training of employees assumed ever greater importance. Today, technical know-how and improved skills, particularly in the field of information and communication (IC), have made existing work processes far more productive. We can also observe that, due to outsourcing and offshoring, different parts of the value chains are spreading out geographically.

Yet, we have not mentioned the most important development in the economy. The real changes are now taking place in the so-called *innovation economy*, in which – besides capital, labor and knowledge – creativity is the fourth principal factor of production. The emphasis on creativity makes the difference. In a knowledge economy logic is predominant, while in an innovation economy everything revolves around imagination.[2] In an innovation economy, processes are not only designed more efficiently (with knowledgeable solutions), above all they are made more effective (with creative solutions). Innovation starts, therefore, with 'management of ideas'. Florida (2003) correctly argues that creativity has become the principal driving force behind sustainable economic growth, and Brown (2003) concludes that the innovation process itself needs to be innovated as well. We can best describe the innovation economy as a creative knowledge economy. An apt description of the activities in an innovation economy is 'creative enterprise with knowledge'. It is not just a question of creativity *or* knowledge *or* enterprise. It is the combination that counts: creativity *and* knowledge *and* entrepreneurship – that is what makes the innovation economy so powerful in generating new business (Berkhout, 2000).

1.1. More than Technology

The whole idea behind innovation is to successfully bring new (systems of) product–service combinations to the market. Market acceptance is, therefore, an essential aspect of innovation. No matter how creative the design and how clever the development behind a technological invention may be, it can never be classified as an innovation if market introduction fails. There can be no innovation without customers.[3] In other words, new product–service combinations may only be viewed as innovations if they fulfill an explicit or implicit social need.

Innovations can also be geared toward production processes. That is what we call process innovation. It involves technological processes (clever manufacturing), logistics processes (clever supplying) and social processes (clever organizing). Process innovation can precipitate great strategic advantages over competitors, not only in terms of costs but also from the perspectives of environment and safety. It is interesting to observe that with integrated process innovation, the outsourcing of production to low-wage countries may be avoided or even reversed. Process innovation is internally oriented, which is why it is also known as invisible innovation. In this chapter, we will argue that process innovation plays a key role in reversing the over-exploitation of planet earth by mankind. Chapter 9 will illustrate this by an example of new technology that may have far-reaching consequences for the chemical industry.

Finally, innovation can also be directed toward the business model. How can I position my company within the entire – often geographically distributed – value chain? Do I change the business emphasis from hardware to software, from products to services? What will I do myself and what will I outsource? How will I cooperate with my partners and suppliers? How will I utilize the creativity of (potential) customers? How do I combine financial targets with environmental goals? It is generally difficult to copy an innovative business model. Indeed, such an innovation is therefore the dream of every CEO (Business Week, 2006).

In the discussion on how to strengthen innovation, industrial sectors often proclaim that more money needs to be spent on technological research. Investing in the production of new technical knowledge – technological progress – is beyond any doubt an essential factor, but one that gives us a one-sided view of innovation. In fact, knowledge of changes in society – societal transitions – and the effect it has on markets is a decisive matter, precisely for innovation. More to the point, the two-way interaction between hard (technical) and soft (social) knowledge is something that needs more attention.

Innovation is, therefore, more than the development of technology. It is a matter of bringing together what is *technically possible* and *socially desirable*. Here, the commercial aspect operates as an integral part of society at large. The behavior of people, as consumers and producers, is central.

1.2. More than Innovation

The purpose of innovation is to generate new business. Therefore, innovation has not only established itself as a *fact* of life for firms to stay competitive, it is also becoming an important instrument for governments to improve the *quality* of life by influencing the way business is done. As a consequence, innovation has to be all about a community's future, about how we plan to realize our ideals. Not only nationally, but also at global scale. It is time we rethink our innovation models. In this chapter, rethinking will be done at different levels of abstraction: from leading innovative organizations to managing technological projects.

2. OPEN LEADERSHIP

Fig. 2.1 shows the basic elements – image of the future, transition path, process model – which are needed to guide change for new business. Leadership provides the function of, and the cement between, these elements.

The traditional way of interpreting leadership – a hangover from the previous century – primarily positions leaders as managers that concentrate on the life cycle of existing products and services. They largely focus on controlling internal production processes and the reduction of costs (Volberda, 1998). That management focus keeps them fully occupied, which is why they hardly get around to key questions like: where do I want

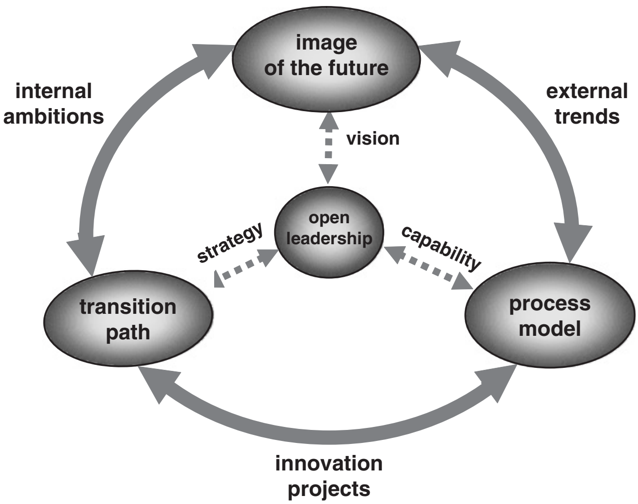

Fig. 2.1. To cope with change, leadership must be future oriented. *Note:* It should give direction to an organization by providing an image of the future, a transition path to roadmap that future and a process model to realize that future. Images of the future, transition paths and process models reveal the way how new business is generated. Therefore, Fig. 1 acts as a framework for new business.

to go with my organization? Do I have the right people for that? What do users demand of my products, now and in the future, and how am I going to tackle external uncertainties? In stock exchange listed companies shareholder-steered thinking has enhanced that kind of *closed* leadership. Administrators are under pressure to realize fast returns (quarterly figures) and to tick off points in complicated legal checklists (compliance rulings). In such companies, the top management level is under tremendous pressure.

Fig. 2.1 visualizes the different aspects of leadership that are needed to manage innovative companies. Leaders must have a *passion* for the future: showing a vision that serves as a beacon for the entire organization, detecting early changes in the market (as an integral part of societal transitions), turning such changes to good advantage in line with their own vision, and convincing shareholders that the right direction is being followed. Leadership must also be *strategic*: making transition paths visible, providing the contours of the company course, defining the required in-house competencies and showing how to combine those with others (who do I need to collaborate with?). And, last but not least, leadership must also be angled at *capability*: selecting people, inspiring people and connecting people to achieve process excellence. Differences in emphasis on the three modules determine the type of leadership. In innovation, the ultimate requirement of leadership is to be successful in realizing new business.

In the following we will see that in situations with high uncertainty, such as innovation, transition paths may be very unpredictable. This means that the road to the desired future should be kept wide open to new concepts. This requires a style of so-called *open* leadership, where it is realized that the transition path should represent a voyage of discovery (innovations build on innovations), and where the quality of the process together with the capability of the organization determine the success along the path.

2.1. Image of the Future

In the Western world, there is no such thing as a formalized view of the future, no integrated vision telling which route to take. Of course, we do not want a mechanistic blueprint, but there are certain notions that indicate the direction we want to follow. There are post-industrial images that direct our thinking and actions, which offer perspectives and vitalize society with renewed energy. These notions are not only linked to financial betterment and material growth, but also to satisfaction and fulfillment. In fact, they particularly involve good stewardship to further improve the quality of life.

What kind of living environment do we leave behind for our children and grandchildren?

Fig. 2.1 demonstrates that an image of the future has two sides. On the one hand, there are the worldwide (changes in) trends and scenarios: for which product–service combinations are large-scale market introductions expected, and at what moment in time? Worldwide, various international institutes have already published a number of technological prognoses and global market explorations.[4] They act as strategic information sources that endeavor to clarify the chances of breakthroughs. They function as an objective framework of reference, as global background information sources.

On the other hand, there are in-house ambitions attached to any image of the future: in what areas does an organization excel, and does it want to maintain its head start in that area and continue to further develop that? Good examples are the priority areas as laid down in the European framework themes, the key areas relating to the Dutch Innovation Platform and the sectors in which a company wants to be a market leader. For example, the electronics firm Philips has opted for the key areas of lifestyle electronics, high-tech lighting and medical equipment. Within those three key areas Philips wants to remain among the best in the field.

The combination of external trends and internal ambitions must result in a focus that provides a direction for organizations to realize a profitable and sustainable business. Note that an image of the future does not specify how to reach that future. It provides a direction only, a beacon, common to the whole organization.

2.2. Transition Path

The transition path visualizes the envisaged road – from the present to the future – by showing the anticipated innovations for the short, medium and long-term. In that way, the roadmap is formulated in terms of time paths that reveal new product–service concepts for the near and far future. This is schematically shown in Fig. 2.2. Within such an integrated innovation program all the various short, medium and long-term projects are linked so that cohesion is created between the envisaged market introductions of new products and services with different time horizons. Note that in this way ambitious business targets are realized in a stepwise fashion. In The European Centre for Innovation (ECI), this approach is called 'kaleidoscopic programming'. In a kaleidoscopic program new innovations will build upon existing innovations.[5]

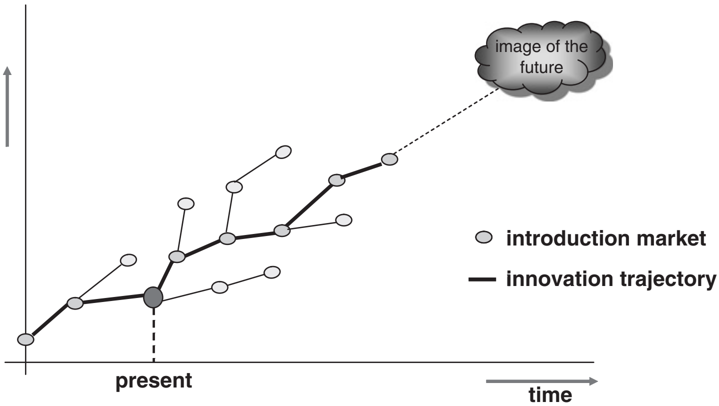

Fig. 2.2. The transition path connects the past via the present with the future. *Note:* Along such a path innovations build on innovations. Therefore, a transition path is not straightforward. It is full of crossings with business dilemmas. A perceived main road may lead to a dead end, and side streets may become a vital part of the main road. In innovation, a transition path should represent a voyage of discovery.

The new business strategy of an organization, given by the roadmap along the transition path, can be judged by looking at how the following dilemmas are being handled:

- short versus long-term projects
- closed versus open networks
- producer versus user solutions

Following Carlota Perez (2002), we are now beyond the turning point of the fifth technological revolution, i.e., the era of IC. According to Ray Kurzweil (2005), we will enter the next technological revolution around 2020, i.e., the era of genetics, nanotechnology and robotics (GNR). Therefore, a balanced innovation strategy should aim at a kaleidoscopic program showing the deployment of IT-technology (short-term projects) and the development of GNR-technology (long-term projects).

Henry Chesbrough (2003) shows that innovation becomes more and more a process that crosses traditional borders, both geographically and organizationally: ‘open innovation’. Companies become aware that the chance of success is higher if excellence within the firm is combined with excellence from outside, leading to global networks of talents. This important trend in innovation will cause a revolution in today’s institutional structures.

Eric von Hippel (2005) shows that users of products and services – both firms and end users – are increasingly contributing to the innovation process: ‘democratizing innovation’. Companies become aware that not only critical lead users but also talented and passionate communities may come up with creative improvements and solutions that are of interest to large markets.

Choices within all three dilemmas – short versus long, closed versus open, producer versus user – determine the innovation strategy of a company, i.e., how to move along the transition path to the preset goals.

In innovation, transition paths are by definition unpredictable. The degree to which things can be steered is limited. Just as with a family tree, some braches come to a dead-end, whilst others perpetuate the line of progress, sometimes due to serendipity. Obviously, such progress is guided by the preset view of the future. Indeed, without any concrete ideas about the future, ambitions would branch off in all directions. This is illustrated by Fig. 2.2. Note that in open innovation, a side street for one company may fit in the main road for another company.

Well-documented transition paths contain vital information that helps companies to better understand the present and, above all, it helps companies to avoid repeating the same mistakes in the future. Therefore, documenting transition paths should be an important part of their new business strategy.

2.3. Process Model

Traditional innovation models describe the processes along the transition path as a pipeline: government investments in scientific research must lead to application-oriented development routes which subsequently – with the aid of risk capital – ought to result in successful market introductions (see Chapter 1). If we invest enough in science and technology then the rest will work out all right, that is the reasoning.[6] Such a linear knowledge-push approach in innovation policies is still taking place on a large scale, with the result that the innovation system cannot flourish.

Chesbrough (2003) shows that the in-house, stage-gate model – a pipeline where promising ideas are developed toward successful products and services, can be extended to a more open version, that allows external interactions from outside the pipeline. This pipeline was extended by Robert Kirschbaum (2005) by introducing the possibility of spin-in and spin-out.

Successful innovation processes are not a matter of one-way pipelines, but rather of interlocking cycles with feedforward and feedback connections: from linear to nonlinear thinking. In that way, a dynamic environment is created in which the soft sciences are linked to engineering, and where the hard sciences connect with valorization goals. The links, which go forwards and backwards (cyclic processes), are an essential feature of dynamic systems (Forrester, 1961; Senge, 1994). To improve the scientific insight into innovation processes, we should make feedback more explicit in our models.

In the foregoing we have argued that in innovation the transition path should represent a voyage of discovery (new innovations build on existing ones) and, therefore, any strategic planning should not be biased toward old thinking but should be wide open for new concepts. Breakthroughs are the result of surprises.

In addition, we have argued that in innovation, large emphasis should be given to the quality of the process and the capability of the organization to execute those processes. Therefore, the remainder of this chapter will be devoted to the process model. We will focus on the nonlinear behavior of innovation processes as they occur along the different stages of a transition path. We will see that improved understanding leads to new insight into how to organize those processes.

3. THE PRINCIPLE OF CYCLICAL INTERACTION

With the explicit addition of feedback paths, models of transitions are represented by two-way interactions, leading to cyclic processes.[7] With the presence of feedback, organizations are continuously exposed to reactions of their environment, providing them with an important source of information and inspiration. In addition – thanks to feedback – organizations are constantly confronted with the consequences of their actions, preferably through built-in 'early signals'. In that way quick adjustments can be made in the event of unexpected occurrences. And, last but not least, the cyclical architecture also ensures that mistakes can be learned from, a very important property for innovation.

In summary, the combination of feedforward and feedback – cyclic interaction – is a fundamental property of dynamic systems. It also provides the basic elements to model the culture in innovative organizations: start quickly, adjust quickly and learn quickly.[8]

3.1. Elementary Building Block

Fig. 2.3 illustrates the basic principle. **A** represents an entity that maintains a cyclical interaction with entity **X**. Examples are interactions between

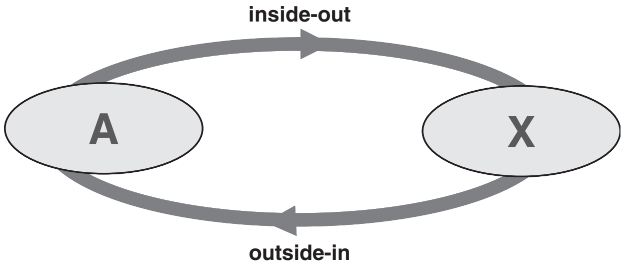

Fig. 2.3. Cyclical interaction is the basis for open innovation and a precondition for operational flexibility. *Note:* It is also a necessary condition for sustainability. Here, A and X represent two interacting entities.

governments and their citizens, commercial organizations and their customers, hospitals and their patients, etc. A particularly interesting example is the innovation strategy of large companies with respect to spinning-out (**A**-to-**X**) and spinning-in (**X**-to-**A**) start-ups. New in-house ideas are developed outside the original business unit and, after successful prototyping, reintroduced in the organization where it all started. It is interesting to note that by including the time axis Fig. 2.3 transforms into a helix. This property is used in Chapter 4.

The cycle in Fig. 2.3 is proposed as an elementary building block (basic unit) for designing nonlinear models to represent innovation systems, similar to those we find everywhere in ecological systems. In particular, open innovation models for technical, economic and socio-cultural change can be constructed from the basic unit in Fig. 2.3.

Looking closer at the basic unit, Fig. 2.4 shows the network version of one cycle. The integration of different resources realizes a preset goal (**A**-to-**X)**, and the specifications of a preset goal determine the resources that are needed to be successful (**X**-to-**A**). Fig. 2.4 illustrates that collaboration of skills is the key to success. Using an optical metaphor, the network acts as a lens that enhances the resources to an optimum in the focal point, representing a high socio-economic value. In a fragmented organization there is no coherence between the resources, and the result will be out of focus.

Note that Fig. 2.4 can also be represented by a spreadsheet or matrix, the columns referring to the resources and each row representing a selection of resources that contributes to a specific goal (Berkhout, 2000).

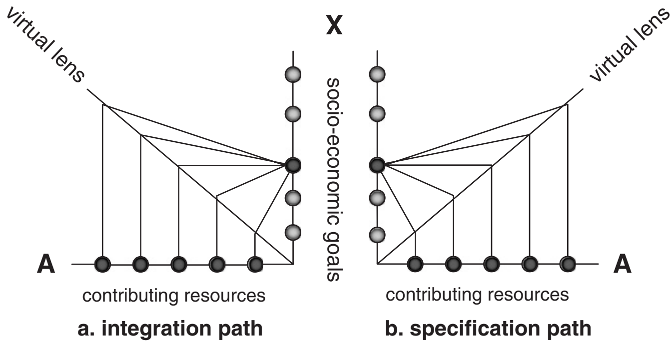

Fig. 2.4. The network version of one cycle, showing the integration and allocation of resources for one specific goal. *Note:* The involved processes are many-to-one (A-to-X) and one-to-many (X-to-A). Using an optical metaphor, the cycle functions as a lens and the goals represent focal points. The network represents focusing (A-to-X) and defocusing (X-to-A).

3.2. Double Dynamics around Technological Research

Fig. 2.5 shows two linked basic units – the double loop – in which technological research plays a central role. The cyclical interaction processes for the development of new technology take place in the so-called technical-oriented sciences cycle (the left-hand side of Fig. 2.5) with the help of a wide range of disciplines from the hard sciences.[9] Technological research in this cycle is a multi-disciplinary activity: a team of scientists from different disciplines of the hard sciences is needed to develop a new technology (many-to-one relationship).

Similarly, the cyclical interaction processes for the development of new products take place in the integrated engineering cycle (the right-hand side of Fig. 2.5). Modern product development is a multi-technology activity: a package of different – often patented – technologies is needed to design and prototype a new product (many-to-one relationship). Like multi-disciplinary science, here too we see that many different specialists are needed to succeed. In most industrial sectors the creativity, knowledge and skills of specialized suppliers play an important role in making the engineering process successful. This is consistent with the open innovation concept.

Fig. 2.5 visualizes that in the hard sciences cycle technological research is driven by new scientific insights: ‘science push’. It also shows that in the engineering cycle, technological research is driven by new functional

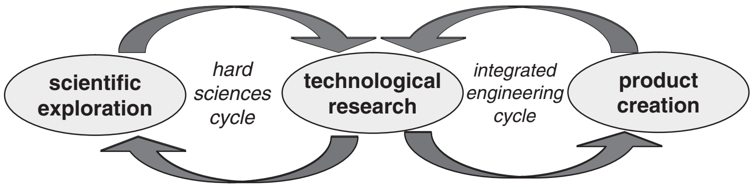

Fig. 2.5. The dynamics surrounding technological research are driven by the cyclical interaction between new scientific insights into technical-oriented processes (Left-Hand Side) and new functional requirements for process–product combinations (Right-Hand Side).

requirements in product development: 'function pull'. The dynamics in technological research are, therefore, driven by new scientific insights as well as new functional requirements. In a well-performing technological infrastructure, scientists and engineers must constantly inspire one another. To achieve this, research must be organized in a different manner: no more barriers between the two cycles. The Technological Top Institutes (TTIs) in The Netherlands are a good example of how this can be addressed: scientists from the hard sciences work together with engineers from industry to create new technical functions ('products'). The Commission of the European Union (EU) has announced plans to start a European Institute of Technology (EIT) at supranational level, based on the push and pull in Fig. 2.5.

It is important to realize that the concept 'products' is used here in the widest sense: everything mankind designs and builds. Hence, it includes immaterial products such as databases, computer software, financial instruments, artistic productions, governmental regulations and governance models. This means that the concept 'technology' is also used in the widest sense: knowledge – both implicit and explicit – on *how to* design, manufacture and maintain products in the widest sense. Broadening the concept of technology and product is characteristic of the proposed open technological infrastructure. The open campus of Philips in Eindhoven is a good example of such an infrastructure.

3.3. Double Dynamics around Market Transitions

Fig. 2.6 also shows two linked cycles, but in this case it is the world of social change rather than the world of technical change that plays the central role. The cyclical interaction processes for the development of new insights into changes in demand – causing emerging and receding markets – take

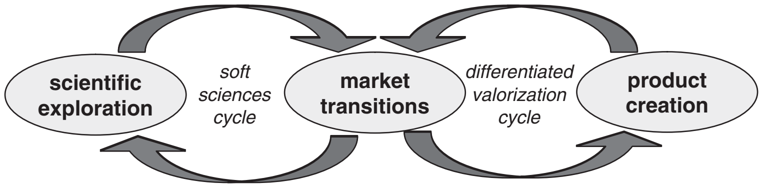

Fig. 2.6. The dynamics around market transitions are driven by the cyclical interaction between new scientific insights in changing socio-economic behavior (Left-Hand Side) and industrial investments in new product–service combinations (Right-Hand Side).

place in the social-oriented sciences cycle (left-hand side of Fig. 2.6) with the help of a wide range of different disciplines from the soft sciences.[10] With these insights, new socio-technical solutions can be developed faster and with less economic risk. Anticipating changes in demand is very much a multi-disciplinary activity: a team of disciplinary experts from the soft sciences is needed to explain and extrapolate shifts in societal needs and concerns as well as shifts in trade conditions (many-to-one relationship). This type of research means a shift in traditional market studies (see Chapter 5).

Likewise, the cyclical interaction processes required to serve the changing society with new product–service combinations take place in the differentiated valorization cycle (right-hand side of Fig. 2.6). Experience shows that in this cycle, users play an important role in making the innovation process successful. This means making use of the creativity of customers: 'democratizing innovation' (von Hippel, 2005). It is interesting to note that in recent years the services sector has expanded considerably, not only because of the greater demand for services from the consumer but also because industry has outsourced many of its support processes. This trend is still going on. If a branch of industry disappears, it is important to realize that the accompanying services will disappear with it.

In the soft sciences cycle, market transitions are seen as a dynamic socio-economic process in which the changing *demand* for product–service combinations is determined by the dynamics of the needs and concerns of society. However, in the differentiated valorization cycle, market transitions are seen as a dynamic commercial process in which the change in the *supply* of product–service combinations is determined by the innovative capability of the business community. In an innovation economy, both components, scientific insight into changing demand (left-hand side of Fig. 2.6) and commercial investment in changing supply (right-hand side of Fig. 2.6), should be constantly inspiring and reinforcing one another.

In industrial innovation programs, a lot of implicit knowledge concerning new technological possibilities is created in the engineering cycle, and the task of the hard sciences cycle is then to make this knowledge explicit: feedback of engineering to the hard sciences. Likewise, a lot of implicit knowledge about market dynamics is created in the valorization cycle, and the soft sciences cycle then has the task of making this knowledge explicit: feedback of valorization to the soft sciences. The explication of implicit knowledge is an important role for science in innovation.

As far as we know, no formal organization has yet been established with the aim of trying to understand, influence and exploit the regime of both technical and social changes in innovation research. This confirms the current imbalance between investment in scientific knowledge for new technology (hard knowledge) and emerging markets soft knowledge, where markets are seen as an integral part of society.

4. THE CYCLIC PROCESS MODEL

If we compare Figs. 2.5 and 2.6, the dual nature of scientific exploration and product creation becomes clear: science has both hard and soft aspects and product creation has both technical and social aspects. Fig. 2.7 combines Figs. 2.5 and 2.6. The result is the Cyclic Innovation Model (CIM), a systems view of change processes – and their interactions – as they take place in an open innovation arena: hard and soft sciences as well as engineering and valorization are brought together in a coherent system of processes. The combination of the involved changes leads to a wealth of opportunities. Here, entrepreneurship plays a central role: making use of those opportunities. Without the drive of entrepreneurs there is no innovation, and without innovation there is not new business. Note that the process model in Fig. 2.7 is one module in the framework for new business (Fig. 2.1).

The first striking feature of Fig. 2.7 is that the architecture is not a chain but a *circle*:

Innovations build on innovations.[11] Ideas create new developments, successes create new challenges and failures create new insights. The creation of value is constantly accumulating.[12]

New instruments will be needed to preserve the strength of the dynamics in the circle. Large-scale failures like the dotcom debacle in 2000 undermine the confidence in the innovation economy and cause investment capital to

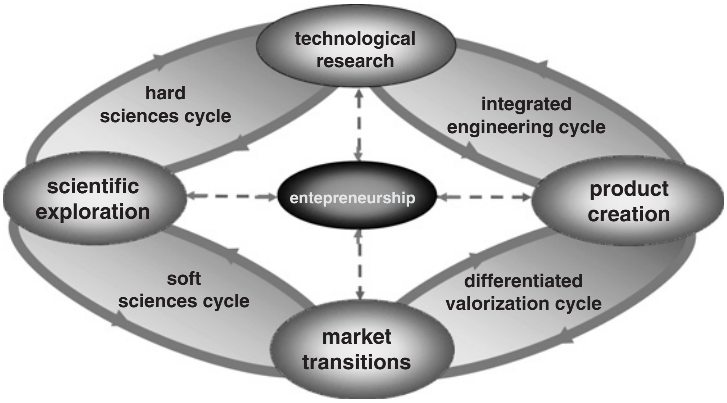

Fig. 2.7. Cyclic innovation model (CIM), presenting the processes in innovation by a circle of change. *Note:* In the model, changes in science (left) and industry (right) and changes in technology (top) and markets (bottom) are cyclically interconnected. It requires an open society to realize a rapid circulation along the circle, clockwise and anti-clockwise. The combination of all these changes creates an abundance of opportunities and it requires entrepreneurship to transform those opportunities into value for society (valorization).

become scarce. In terms of the cyclic process model: the processes of change are decoupled. The economy enters a phase of stagnation in which companies focus on existing business at lower cost (life-cycle management), until institutional adaptations are made and investment capital becomes available again to spur innovation. The dynamics in the circle then accelerate again. Carlota Perez (2002) calls this phase the turning point in a technological revolution.

Fig. 2.7 also shows that the proposed model portrays a system of dynamic processes – circle of change – with four 'nodes of change': scientific exploration, technological research, product creation and market transitions. But more importantly, between these nodes there are 'cycles of change' by which the dynamic processes in the nodes influence each other. In other words, they inspire, correct and supplement each other (first-order dependency).

This produces a system of linked cycles, which in turn also influence each other (higher-order dependencies). The result is a more or less synchronized regime of interconnected dynamic processes that spark a creative interaction between changes in science (left-hand side) and industry (right-hand side), and between changes in technology (top) and market (bottom). The combination of change and entrepreneurship is at the basis of innovation. In Chapter 3, we attach the names of prominent entrepreneurial scientists to the cycles of the process model, with the objective to increase the understanding of the fundamental concepts depicted in this model.

Autonomous social transitions manifest themselves in markets as changes in the need for products and services (the demand). Think of the huge influence of education and emancipation on a society. On the other hand, autonomous technological developments generate new products and services (the supply). Think of the huge influence of internet and mobile communication technology on a society. It is the cyclic interaction of both autonomous innovation drivers, social and technical, that will create new business with a maximum value for society.

Several variations exist in the proposed cyclic process model, depending on which goals we would like to achieve. For instance, if we would like to emphasize changes in society at large – combining economic and social values – then 'market transitions' should be replaced by 'societal transitions' in Fig. 2.7. Similarly, if we would like to emphasize changes in today's energy system – aiming at renewable sources – then 'market transitions' should be replaced by 'energy transitions'.

For the coming decades, environmental values will become one of the biggest drivers in innovation worldwide. This means that the transition node in the cyclic process model should be focused on changes in the global ecological system: 'ecological transitions'.

4.1. Meeting Place for Science and Industry

Returning to von Hippel's democratizing innovation concept, it is clear that in the valorization cycle users should play a vital role. This is represented by the feedback loop in the lower right part of the circle. If we extend this concept with the aid of the cyclic process model, it means that the democratizing concept is applicable to all cycles. Every node is an open node and every feedback loop contains a contribution by users in the neighboring nodes.

It is important to realize that all cycles in Fig. 2.7 may also function in a *virtual* space. If we focus on foresighting, the hard sciences cycle should give a view of what kind of technological possibilities we may expect in the future. The result provides input to the virtual engineering cycle, to create – with the help of passionated designers – images of new product–service combinations (clockwise extrapolation starting from the hard sciences).

Similarly, the soft sciences cycle should give a view on what kind of needs and concerns we may expect in the future. The result provides input to the virtual valorization cycle, to create – with the help of passionated users – product–service combinations (anti-clockwise extrapolation starting from the soft sciences). It is the virtual space of product–service images where science and industry should meet each other. Those images do not present rational constructions but they tell emotional stories.

Take, for example, innovations in the health care (HC) sector that will be made possible by new developments in the IC sector (transsectoral innovations): the top half of Fig. 2.8 (future developments in IC technology) meets the bottom half of Fig. 2.8 (future needs and concerns in the health care market).

Universities, together with industry, could already start similar exercises for the sixth technological revolution. Governments should stimulate those future-oriented initiatives.

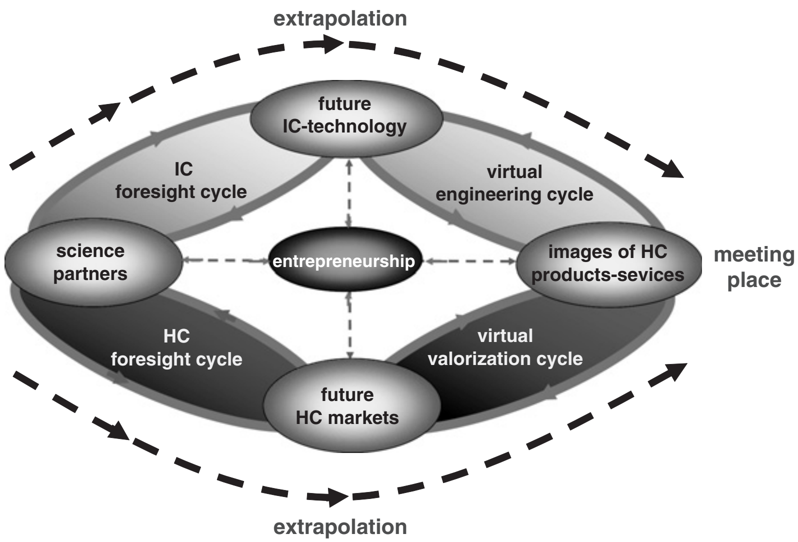

Fig. 2.8. Example of sector-crossing foresighting. *Note:* The upper part of the process model shows the extrapolation activities of hard scientists in the information and communication (IC) sector; the lower part shows the extrapolation activities of soft scientists in the health care (HC) sector. The result is a common virtual product–service space. This is the preferred space where science and industry should meet to innovate health care.

Foresighting with the CIM will be discussed in more detail in Chapter 4. Note that by including the time axis, the 'circle of change' is extended to a four-fold 'helix of change'.

4.2. Networks of Skills

Looking closer at the cyclic process model opens up the nodes and cycles. This is similar to what was already shown in Fig. 2.4. Every node represents a collection of different resources that form cyclical networks with other resources in neighboring nodes.

Fig. 2.9 visualizes that innovation processes take place along a circle with more or less synchronized networks – so-called CIM networks – in which knowledge suppliers, design firms, supply companies, production companies, marketing organizations and user communities reinforce each other's activities (see Fig. 2.9). The communication in these open networks of skills is increasingly empowered by new capabilities of the IC sector. Institutional factors, in particular governmental regulations, have a dramatic effect on the dynamics within and between the CIM networks. Ultimately, institutional factors determine the maximum rate of circulation that can be realized along the circle. The way a society is organized and regulated can exercise an enormous influence on this process, in both a positive and a negative sense.

Fig. 2.9 also visualizes how the multitude of highly diverse processes can be organized to reinforce each other. Using again the optical metaphor, Fig. 2.9 can be represented by four lenses that focus the multi-resource input. A focal point of one lens acts again as a new resource for the next lens. Note that one lens represents the capability of a network. If lenses do not work well, the points are blurred and the socio-economic goals will be out of focus.

Note that Fig. 2.9 can also be viewed by four interconnected spreadsheets or matrices. Using the multi-matrix presentation, the necessity of interconnectivity of skills can be well visualized (Berkhout, 2000).

5. CLASSIFICATION OF INNOVATIONS

The circular arena in Fig. 2.7 shows that new innovations arise from previous generations. New innovations are, therefore, a mixture of the old and the new, and the ensuing impact can be large or small; the terms generally used are incremental and radical innovations. This is not a very clear distinction. The process model of CIM shows that innovations can be subdivided into different classes. This classification may be more

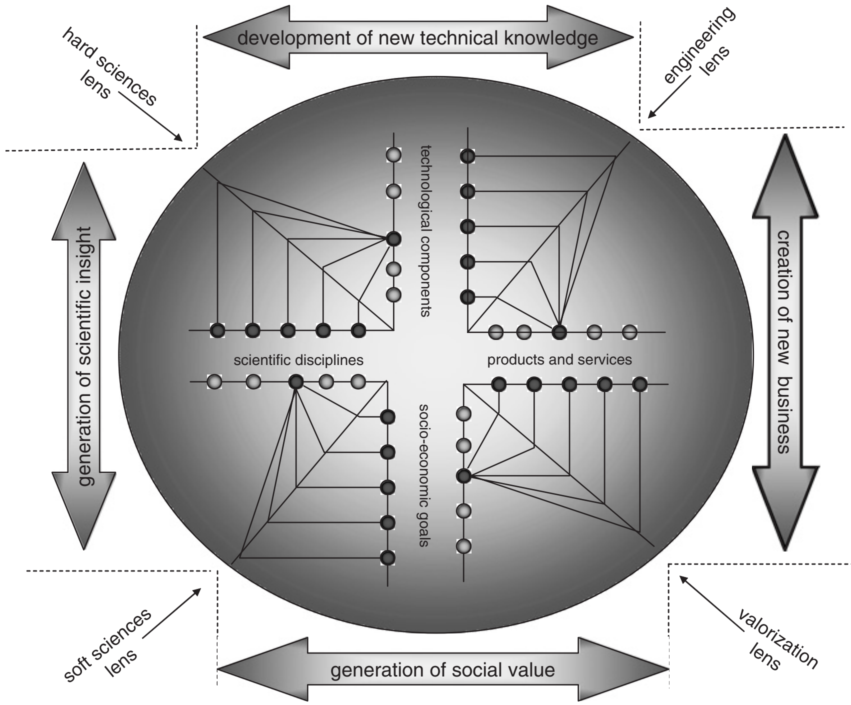

Fig. 2.9. Looking closer at the cyclic process model. *Note:* The circle of change represents interacting networks of skills, showing the complexity of an open innovation system (beyond the pipeline architecture). The output of one network generates the resources for the neighboring network. Here, this process is visualized in a clockwise fashion. Organizational flexibility is the key to success.

informative. We will use the terminology of Carlota Perez (2002) – utilization of existing technology or 'deployment' – and Edward Cornish (2004), development of new technology or 'futuring'.

5.1. Deployment Category

Class 1 innovations are the result of new developments in a single node. These involve existing product–service combinations, where only the market concept is radically changed. Examples are switching to internet shops, focusing on a different market segment and responding to a new lifestyle. It appears that the 'Second Life' movement is the most recent development for Class 1 innovations.

Class 2 innovations are the result of new developments in two nodes. These involve the development of new product–service combinations together with a unique market concept. Examples include technical installations with intelligent sensors connected directly to the internet (connected products). This new combination creates significant added value since information about access, use/abuse and the physical condition of installations becomes available wherever and whenever it is needed (early warning signals). The result is that entirely new services become possible, which in turn means that the traditional product-oriented market concepts will have to be replaced. Other examples are capabilities in mobile identification technology (RFID), which will bring about major improvements in logistics as well as a major change in the battle against crime and terrorism.

5.2. Futuring Category

Class 3 innovations follow from new developments in three nodes. They involve the development of new technologies, which in turn make new product–service combinations possible, which for their part call for new market concepts. Many emerging IC technologies in broadband interaction will make spectacular Class 3 innovations possible, such as telecare in the widest sense. And recent developments in the life sciences have generated new opportunities in biotechnology, which in turn set off a revolution in the development of new product–service combinations in the pharmaceutical and food industries. But spectacular progress is also being made in the nanosciences, where technical building blocks are on a molecular scale. Nanosciences have already produced radical new knowledge for material-oriented nanotechnologies, which will in turn cause a revolution in the development of product–service combinations in all technical-industrial sectors. An example would be nanotechnology for the new energy era, characterized by internet-like decentralized power networks.

Class 4 innovations follow from new developments in *all* nodes. Innovations based on the scientific research in genetics, nanosciences and artificial intelligence will change society so radically that the overwhelming increase in technological possibilities (top half of Fig. 2.7) will have to be accompanied by a major effort to increase our understanding of society's needs and, above all, society's concerns (bottom half of Fig. 2.7). Climate change, for example, will require a great deal of cohesion in the development of knowledge in the hard and soft sciences.

6. SYSTEM FAULTS IN THE INNOVATION ARENA

In a closed society there exist principal barriers in creating new business, usually owing to institutions that were established in the previous technological revolution. Figs. 2.10 and 2.11 illustrate two notorious obstacles that are referred to here as 'scientific isolation' and 'technology push'.

Scientific isolation refers to a society that may be excellent in scientific research, but still underperforms economically because of a communication barrier between the science and industry community (Fig. 2.10). The two worlds make their own choices and plans, and throw their wishes and results over the fence to the other side.

Technology push refers to a society that may be excellent in designing and building technical functions but still underperforms socially because of a communication barrier between the technical and social community (Fig. 2.11). Both worlds make their own choices and plans; here too they throw their wishes and results over the fence to the other side.

The failure of the Lisbon strategy of the European Union is a consequence of the existence of these obstacles in the European innovation system. The huge emphasis on more research and more technology is a too one-sided and simplistic approach. The proposed multi-layer environment for new business shows that the real problem lies elsewhere: lack of open leadership (Fig. 2.1),

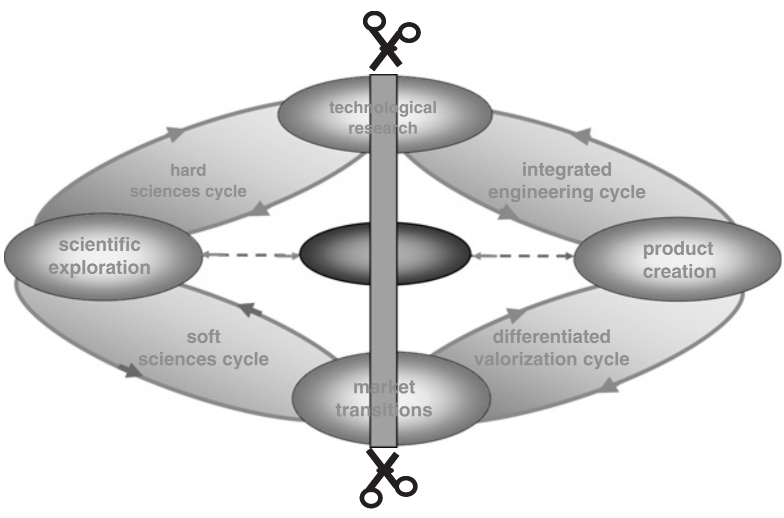

Fig. 2.10. A society can be excellent in science, but still may underperform economically (Vertical Communication Barrier).

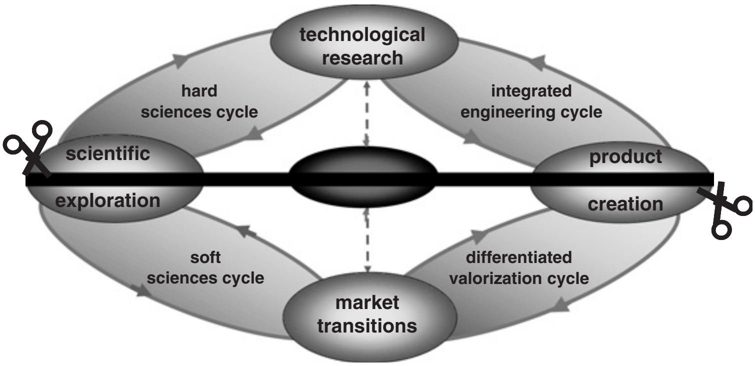

Fig. 2.11. A society can be excellent in technology, but still may underperform economically (Horizontal Communication Barrier).

too narrow transition paths (Fig. 2.2), little emphasis on nonlinear processes (Fig. 2.7) and insufficient trans-border interactions (Figs. 2.10 and 2.11).

The solution lies in connecting technological progress with societal needs as well as loosening top down control and tightening bottom-up collaboration. In a recent article, Rosabeth Moss Kanter (2006) summarizes many years of her consulting experience on innovation for a large diversity of companies. Her extensive practical experiences are confirmed by the theoretical considerations in this chapter.

6.1. Different Levels of Abstraction

In the foregoing, we have presented the integrated environment for creating new business at different levels of abstraction:

1. *Framework for new business*
2. *Cyclic innovation model*
3. *Open technological infrastructure*

Fig. 2.12 shows this in a schematic manner. At the highest level it is all a matter of giving direction to the future by providing an image of the future, showing the strategic contours of the company course to that future by providing a transition path, and specifying the capability requirements of the organization to realize that future by providing a process model (Fig. 2.1). At the second level, we find the actual innovation arena showing the CIM – in terms of a circle of change – with two-way interactions

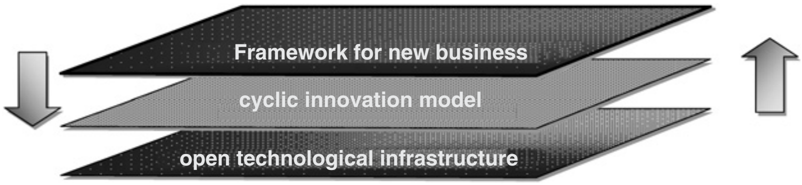

Fig. 2.12. The integrated environment for creating new business has been presented at three levels of abstraction. *Note:* To continuously benefit from emerging changes and opportunities, leaders of innovative companies should simultaneously act at the different levels. It means constantly moving through the system.

between the hard sciences and social issues as well as the soft sciences and engineering issues (Fig. 2.7). And at the third level, the lay-out of the open technological infrastructure has been positioned. This level shows that the dynamics of technological research is driven by new scientific insights as well as by functional requirements for new products and services (Fig. 2.5).

Fig. 2.12 shows that the technological infrastructure is part of the innovation model, and the innovation model is again part of the framework for new business. This hierarchy, business–innovation–technology is considered to be an essential feature of our innovation concept.

Finally, if we look into the future of international business, a new socio-economic regime is required, where innovation processes realize smart technical solutions that demand a low amount of natural resources and that involve small emission and waste. This innovation effort is represented by the upper part of Fig. 2.7. In addition, we must move to a new socio-economic regime where innovation realizes a smart regulatory system that opens up and favors large markets for ‘green’ products and services. This innovation effort is represented by the lower part of Fig. 2.7. Recollecting Fig. 2.1, the highest level of the new business environment, it all starts with leadership that has passion for a sustainable future.

NOTES

1. The term knowledge is used here in the broadest sense: to be informed, to understand why, and to know how. Know-how can be explicit or implicit or a mixture of both.

2. It is appropriate to quote Albert Einstein here: ''Logic brings us from A to B, but imagination takes us everywhere''.
3. The term 'successful innovation' is thus a pleonasm.
4. See for example www.TechCast.org.
5. See www.centre4innovation.eu.
6. The innovation policy in the European Union aims at R&D budgets of the member states that amount to at least 3% of their GNP.
7. A cycle consists of processes occurring repeatedly, each time with new starting conditions and a changing context. The dynamics in a cycle are determined by the cycle time and the amount of change per cycle.
8. It is appropriate to quote Charles Darwin here: 'the ones that survive are those that adapt'.
9. Disciplines from the hard sciences include specialist knowledge in the natural and life sciences.
10. Disciplines in the soft sciences include specialist knowledge in behavioral and social sciences.
11. Innovation guru Tom Peters (1997) also makes use of the circular architecture, displaying 15 ideas around a 'circle of innovation'.
12. The accumulation of innovations is visualized by the transition path.

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CHAPTER 3

FROM PASTEUR'S QUADRANT TO PASTEUR'S CYCLE; LABELING THE FOUR BASIC CYCLES OF CIM WITH CHAMPIONS

ABSTRACT

Donald Stokes' approach to map the names of prominent scientists onto a diagram showing their impact on fundamental science and applied science is adopted and expanded to illustrate the dynamic interactions of the four nodes of the Cyclic Innovation Model (CIM). Tagging names of prototypical role models onto the four nodes and cycles of CIM increases the meta-level understanding of the fundamental concepts depicted by this innovation model. It also serves as a tool to validate the completeness of the model.

1. INTRODUCTION

Immediately after World War II, Vannevar Bush, Director of the Office of Scientific Research and Development, presented his influential report entitled

The Cyclic Nature of Innovation: Connecting Hard Sciences with Soft Values
Advances in the Study of Entrepreneurship, Innovation and Economic Growth, Volume 17, 49–68

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Science, The Endless Frontier (Bush, 1945), which outlined a framework for thinking about science and technology. Bush coined the phrase 'basic research' which he defined as follows: "Basic research is performed without thought of practical ends. It results in general knowledge and an understanding of nature and its laws." (Bush, 1945, Chapter 3). He believed that constraints of practical use would hamper creativity in basic research, and he was a strong advocate of the linear model in which "basic research is the pacemaker of technological progress." (Bush, 1945, Chapter 3). This view underlies the first generation innovation models (see Chapter 1), which were strictly linear cause-and-effect constructions in which basic research fuels applied research, and applied research leads to new products (or processes). The belief in this linear pipeline model was so strong that it was simply assumed that investments in basic research would eventually yield returns in the form of useful products and processes. In essence, this model resembles a cow, where grass entered on the one end yields milk at the other end. But as the black-and-white box remained firmly closed, the mechanism by which basic research turns into market value remained a mystery.

In the early post-war years, numerous examples appeared to confirm this view, and therefore Bush's conceptual leap did not seem ad hoc or unjustified. The linear pipeline was obviously successful. Occasionally, the time between fundamental research and the emergence of an actual application was quite long. When Albert Einstein developed his theory of special relativity (Einstein, 1905), no one had the slightest foresight of any practical applications. One important implication of the theory of special relativity is the equivalence of matter and energy, expressed by arguably the world's most famous equation: $E = mc^2$. Energy is directly proportional to the mass times the square of the speed of light. This implies that one can be converted into the other, and vice versa. On July 16, 1945, this became dramatically clear when the first atomic bomb was detonated in a remote desert in New Mexico (Rhodes, 1986). Forty years after Einstein's fundamental research, a practical application had been developed.

2. PASTEUR'S QUADRANT

The division of science into fundamental science and applied science gave rise to a one-dimensional spectrum between the two extremes (Fig. 3.1). It was assumed that scientists could be positioned somewhere along this line, depending on the character of their scientific work. While it is easy to

Fig. 3.1. One-dimensional science spectrum, ranging from fundamental science to applied science. In this classification scheme, scientific research cannot be more fundamental without automatically being less applied. (Adapted from Stokes, 1997).

position scientists like Niels Bohr and engineers like Thomas Edison on this one-dimensional spectrum, a dilemma arises when the same is attempted for someone like Louis Pasteur. In his book *Pasteur's Quadrant* (1997), Donald Stokes selected Pasteur as the prototypical example of a scientist who cannot be classified in this way. Former director of the Science Resource Studies at NSF, Charles Falk, phrased it as follows: "any process that divides a continuum into discretely demarcable regions is generally plagued by fuzziness and overlaps at the boundaries of the subdomains." (Falk, 1988). No single point on this line can represent Pasteur's endeavors to understand the microbiological processes and his efforts to apply them in practice. There is no location on the one-dimensional spectrum that does justice to his scientific accomplishments.

Stokes argues that, in the old paradigm, there are two solutions, neither of which is particularly satisfying. The first solution is to place Pasteur at both extremes. But this, according to Stokes, leads to "the anomaly of Pasteur being represented by two Cartesian points in this Euclidian one-space". The other solution is to place Pasteur midway between basic research and applied research. While this suggests that Pasteur is both a basic and an applied researcher, it just as strongly indicates that he is neither. This brings us back to the initial shortcoming of a one-dimensional classification, namely that more of one characteristic automatically implies less of the other. It is impossible to represent a scientist who excels in both basic research and applied research by a single point on a line which extends between these two distinctions.

Stokes' clever insight was to question the validity of this linear distinction and the implied separation between basic and applied research. His solution is as simple as it is elegant: convert the linear classification into a two-dimensional matrix by rotating the one-dimensional axis at the halfway point, as illustrated in Fig. 3.2. The vertical axis now represents increasing fundamental understanding, while the horizontal axis represents increasing applicability. The labels 'fundamental' and 'applied' are replaced by 'science

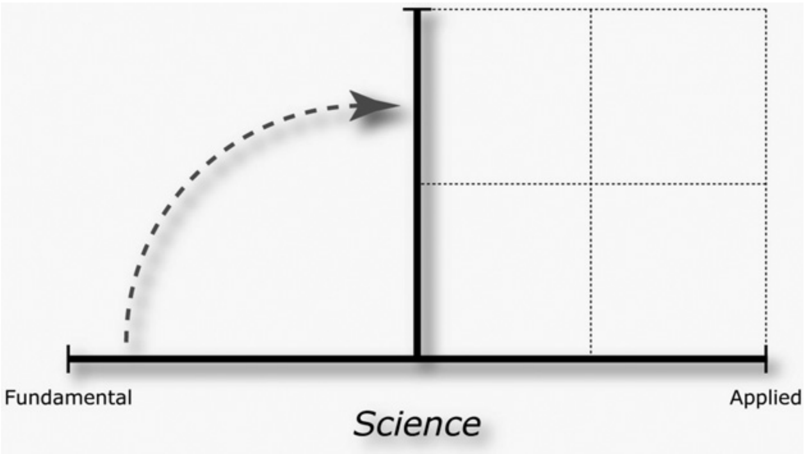

Fig. 3.2. Rotation of the linear classification by 90° around the midway point between fundamental science and applied science yields a two-dimensional matrix in which both aspects are orthogonal and thus independent of each other. No longer is more of one characteristic automatically less of the other. (Adapted from Stokes, 1997)

inspired by the quest for fundamental understanding' and 'science inspired by considerations of use', respectively. Because the axes are orthogonal, they are independent of each other. Science characterized by the quest for more fundamental understanding is no longer automatically science with less consideration for use. Even though the plane spans a two-dimensional continuum, Stokes simplified the classification by dividing it into four quadrants. To increase the conceptual understanding of his framework, Stokes named the quadrants after prototypical and well-known individuals whose characterizations as scientists and/or engineers placed them at the corresponding cell in the matrix. The top-left quadrant represents pure basic research, "guided solely by the quest for understanding without thought of practical use. It might be called Bohr's quadrant in view of how clearly Niels Bohr's quest of a model atomic structure was a pure voyage of discovery" (Stokes, 1997, p. 73). The bottom-right quadrant represents pure applied research. "It would be appropriate to call it Edison's quadrant, in view of how strictly this brilliant inventor kept his co-workers […] from pursuing the deeper scientific implications of what they were discovering in their headlong rush toward commercially profitable electric lighting"

(Stokes, 1997, p. 74). And finally, the raison d'être for this entire exercise, the top-right quadrant (representing use-inspired basic research) is named after Louis Pasteur: Pasteur's quadrant.

Stokes did not name the lower-left quadrant, which represents science which is not driven by a quest for fundamental understanding and has no considerations of practical use. We follow Van der Linden (1999), who replaced Stokes' yes/no distinction on both axes by the more subtle high/low characterization. He also named the lower-left quadrant after ornithologist Roy Tory Peterson. As an example of research in Peterson's quadrant, Van der Linden mentions making an inventory of the occurrence of different species of birds over the continents. Such research ranks low in the quest for fundamental understanding, and low on the considerations for practical use. Van der Linden also replaced Bohr by Einstein, as the latter is much more well known. Fig. 3.3 shows the modified Stokes matrix.

3. IDENTIFYING THE FOUR FUNDAMENTAL CYCLES OF CIM

The Cyclic Innovation Model (CIM) consists of four basic nodes, connected through four basic cycles of interaction (Berkhout, 2000; see also Chapter 2). We adopt Stokes' approach to map the names of prominent scientists onto a two-dimensional matrix delineating fundamental science and applied science, and apply it to the cyclic interaction between the hard sciences node and the technology node in CIM. As in Stokes' original design, the quadrant with a low impact on both the quest for fundamental understanding and the considerations of use is dropped as it serves no useful purpose. The three relevant quadrants are molded into the structure of the hard sciences cycle, located at the top-left in CIM. This cycle is appropriately named Pasteur's Cycle (Section 3.1). Next, the concept of naming after champions is expanded to the other nodes and cycles of CIM. Tagging names of prototypical role models onto the four nodes and cycles of CIM increases the meta-level understanding of the fundamental concepts depicted by this innovation model.

3.1. The Hard Sciences Cycle (Pasteur's Cycle)

The old paradigm regarded applied science quite literally as the application of fundamental science. In that view, technology relied on fundamental

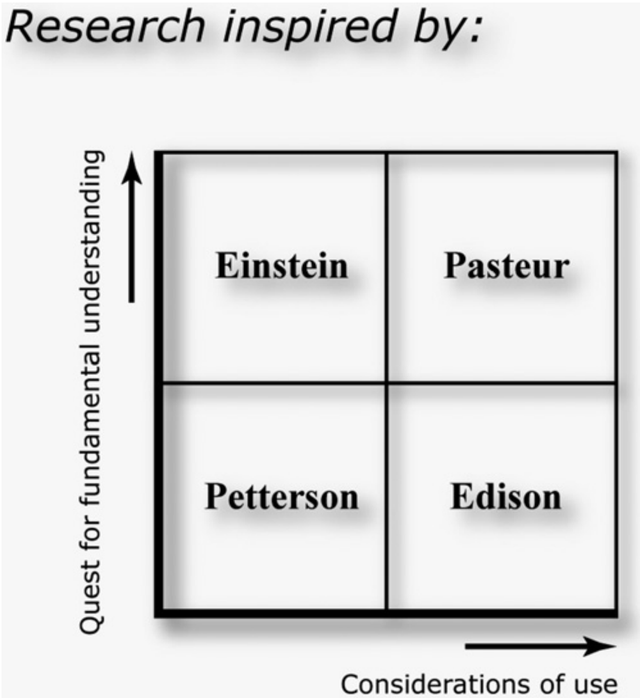

Fig. 3.3. Stokes' two-dimensional classification scheme enables the placing of scientists in one of four quadrants, according to their contributions in the two now orthogonal aspects: Their quest for fundamental understanding (Formerly: Fundamental Science) and their considerations of use (Formerly: Applied Science). In this matrix, Pasteur occupies the top-right quadrant, which does justice to his contributions to both fundamental science and applied research. Stokes coined it 'Pasteur's Quadrant' (Adapted from Van der Linden, 1999).

research and hence it could not precede it in its development. However, much fundamental science is undeniably inspired by technology. For example, the continuous miniaturization of semiconductors was mostly technology driven, until the process reached certain physical limitations. Fundamental science was required to develop new ways to pack more components onto a microchip: feedback from technology to science. Intel, the world's largest semiconductor manufacturer, does not have sufficient in-house knowledge of fundamental sciences to move such technology boundaries (Chesbrough, 2003). Another example of technology preceding fundamental science is the optimization of steam engines. Engineers had optimized the efficiency of steam engines without any underlying theory of thermodynamics. That theory was developed afterwards by scientists like Sadi Carnot, who actually studied existing steam engines (Carnot, 1878). There are also many cases of phenomena which were already used in practical applications long before they were fundamentally understood. For example, vacuum switches in electrical circuit breakers have been in use for several decades, but only recently it was discovered how they work (Lanen, Popov, Van der Sluis, & Smeets, 2005). Reversing the traditional linear cause-and-effect pipeline from fundamental to applied science, one could argue that the purpose of fundamental science is to explain the workings of applied science: fundamental science and applied science have a cyclic interaction.

Stokes cast Louis Pasteur as the prototypical example of a scientific engineer, or an engineering scientist. Pasteur excelled in both fundamental science and applied research, and he frequently initiated research in one domain on the basis of his discoveries in the other. When applied research sprouted fundamental questions, Pasteur resorted to fundamental science to find the answers. These answers in turn became the source of new practical applications of this deeper understanding. According to James Bryant Conant, who wrote a case study on Pasteur from which Stokes borrowed most of his examples, Pasteur's approach toward applied science was characterized by "reducing the degree of empiricism in a practical art" (Conant, 1952).

The two-way interaction between fundamental understanding and practical use in the work of Pasteur is illustrated by the following example given by Stokes. An industrialist experienced problems in the production of alcohol from beets through fermentation. Pasteur examined samples of the fermenting beet juice, and discovered that the fermentation process was caused by anaerobe microorganisms that require no free oxygen. By extracting oxygen from the sugar molecules, the microorganisms turn beet sugar into alcohol. Pasteur discovered that fermentation is a process in which living 'chemical factories' convert sugar into alcohol. If these microorganisms die, the production of alcohol ceases (Stokes, 1997; see also Geison, 1995).

The hard sciences cycle is located at the top-left in CIM, and connects the scientific exploration node with the technological research node. The scientific exploration node might be named after Albert Einstein (1869–1955), arguably the world's most famous scientist. Einstein was a theoretical physicist, primarily motivated by the quest for a deeper understanding of the laws of the universe. Even though he started his career as a technical examiner at the Swiss Patent Office, Einstein hardly ever considered the practical application of his theoretical work. Nevertheless, in 1926 Einstein co-invented and patented a refrigerator (Dannen, 1997). Einstein's theory of special relativity laid the foundations for the atomic bomb and nuclear power plants. His theory of general relativity is essential to the accuracy of the Global Positioning System (GPS).

The technological research node might be named after Nikola Tesla (1856–1943), the Serb-American inventor, physicist and mechanical and electrical engineer who is generally regarded as one of the most important inventors in history. Most of his inventions were in the field of electricity and magnetism, and he laid the groundwork for the present day alternating current (AC) electric power systems. In 1943, the Supreme Court of the United States ruled that Tesla is the inventor of the radio (Tesla, 2006). He is also considered to have invented the telephone and the loudspeaker. In his honor, the *Système International d'unités* (SI) has named the unit of magnetic flux density Tesla.

The interaction between the scientific exploration node and the technological research node is represented by the hard sciences cycle, which we named after Louis Pasteur (1822–1895), the French chemist and microbiologist. Pasteur used his fundamental knowledge (*know why*) to create new technology (*know how*). Further motivation behind this choice as a role model for the hard sciences cycle was already given at the beginning of this section. Fig. 3.4 shows Pasteur's cycle in CIM.

3.2. The Integrated Engineering Cycle (Edison's Cycle)

Stokes' original argument for naming the pure applied research quadrant after Thomas Edison (cited in Section 3.1), is more appropriate for the integrated engineering cycle of CIM. The integrated engineering cycle is located at the top-right in CIM, and connects the technology node with the product creation node. Here, the technological research node might be named after the Palo Alto Research Center (PARC), the famous Xerox R&D laboratory founded in 1970 by George Pake. Researchers at PARC invented some of the most fundamental components of modern personal computer systems, including the laser printer, Ethernet, InterPress (a precursor of PostScript) and the graphical user interface (GUI). Even though the computer mouse was not invented at PARC, it was adopted by researchers at PARC as the device for controlling the GUI. According to

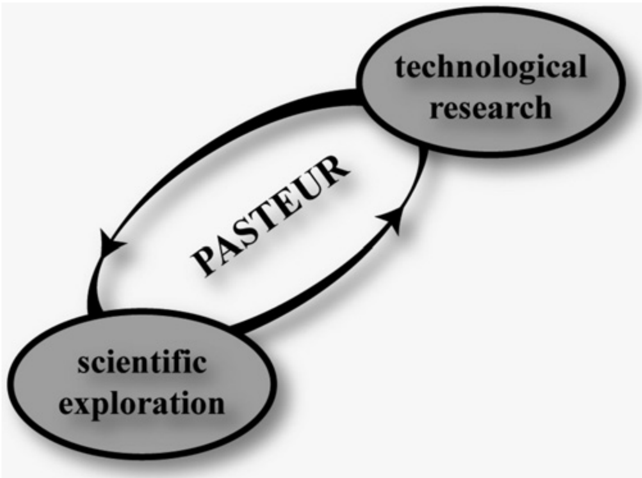

Fig. 3.4. Pasteur's cycle connects the scientific exploration node with the technological research node. Louis pasteur is the role model for the two-way interaction between scientific exploration and technological research. The combined feedforward and feedback loop is called Pasteur's Cycle.

most business historians, PARC is the prime example of a company (Xerox) with excellent R&D facilities, yet unable to convert its ideas into commercial products.

The product creation node might be named after Henry Ford (1856–1943, the founder of the Ford motor corporation) who developed assembly-line manufacturing and mass production of inexpensive automobiles. Ford paid his workers high wages ($5 a day, in 1914), and he considered consumerism the key to peace (Ford, 2006). In 1918, merely ten years after the introduction of the Ford Model T, half of all the cars in the U.S. were T-Fords. In 1927, a staggering more than 15 million Model T Fords had been sold.

The two-way interaction between the technological research node and the product creation node is represented by the integrated engineering cycle, which we named after Thomas Alva Edison (1847–1931), the famous American inventor and businessman. Edison has some 1,100 U.S. patents to his name, but more notably turned many technologies developed by others into products which greatly influenced life in the twentieth century. Amongst his many contributions are the introduction of electric light (the light bulb *and* the indispensable electricity network), the telephone, the

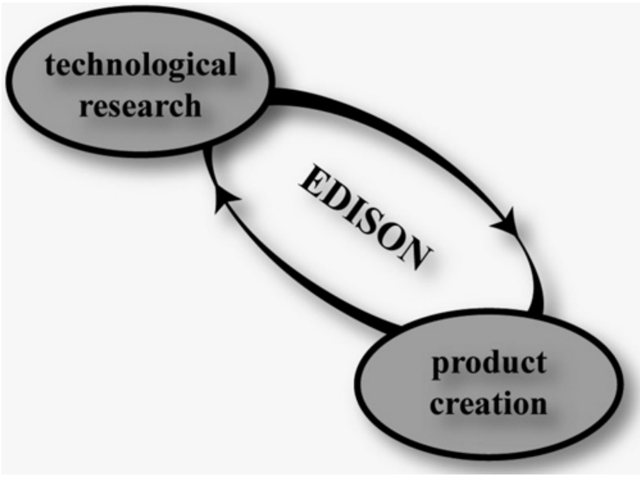

Fig. 3.5. Edison's cycle connects the technological research node with the product creation node. Thomas Edison, the great american inventor and businessman, is the role model for the two-way interaction between technological research and product creation. The combined feed-forward and feedback loop is called Edison's Cycle.

phonograph (gramophone), and the two-way telegraph. In 1997, *Life* magazine placed Thomas Edison as # 1 in their list of the '100 Most Important People in the Last 1000 Years'. Fig. 3.5 shows Edison's Cycle in CIM.

3.3. The Open Valorization Cycle (Gates' Cycle)

The open valorization cycle is located at the bottom-right in CIM, and connects the product creation node with the market transitions node. The product creation node might be named after Sir Clive Marles Sinclair (1940–), the British inventor, product developer and entrepreneur. Amongst his most successful products are the ZX Spectrum (Britain's best selling computer in the early 1980s) and the A-bike (a light-weight foldable bike). Sinclair also launched many products that failed commercially, such as The Zike (a light-weight electric bicycle), which sold only 2,000 units while a production rate of 10,000 units a month had been expected (Sinclair, 2006).

The market transitions node might be named after Michael Saul Dell (1965–), the founder and chairman of the Dell Computer Corporation, which reported a revenue of $59 billion in 2006. While being criticized by Apple Computers' founder and CEO Steve Jobs for making "un-innovative beige boxes" (Dell, 2006a). Michael Dell innovated the computer retail business model by offering custom-assembled computers at prices lower than retail brands and delivering directly to customers. Dell has no retail stores but employs a direct sales model using the phone and the internet. Dell receives payment for their products *before* it pays for the components that make up those products (negative cash conversion system). Dell is a follower rather than a product innovator, but because of the size of its market share the company exerts an important influence on standards in the personal computer market. For example, whereas Dell had only used Intel processors in the past, the company recently announced that it will start using AMD microprocessors as well (Dell, 2006b). Dell's decision to support Blu-ray rather than HD DVD adds a lot of weight to the Blu-ray side of the balance in the battle between the two emerging successors to the DVD format (Dell, 2006c).

The two-way interaction between the product creation node and the market transitions node is represented by the open valorization cycle, which we named after William Henry Gates III (1955–), co-founder and former CEO of Microsoft, the world's biggest and most influential software company. A Harvard drop-out, Bill Gates set the first important step to his world dominance of software for personal computers by providing the operating system (PC DOS) and a BASIC interpreter for the IBM PC, which was launched on August 12, 1981 (IBM, 2006). After a number of early, not very successful versions of a graphical user interface (GUI), Microsoft Windows 3.0 (released in 1990) provided the big breakthrough to the graphics-based operating system environment. Together with its de facto standards in word processing (Word), spreadsheets (Excel) and presentation software (PowerPoint), Microsoft became the most important software developer in the business. Bill Gates created an entire new workspace, at home and in the office.

In June 2006, Microsoft employed over 71,000 people worldwide (Microsoft, 2006). The much debated stranglehold that Microsoft exerts on the computer market should also be seen in a different context. First, Microsoft's commitment to backwards compatibility is equaled only by Intel. Both companies have ensured, at the expense of being less innovative than they could have been, that 25-year old software written for Intel's 8080 processor running MS DOS still runs today under Microsoft

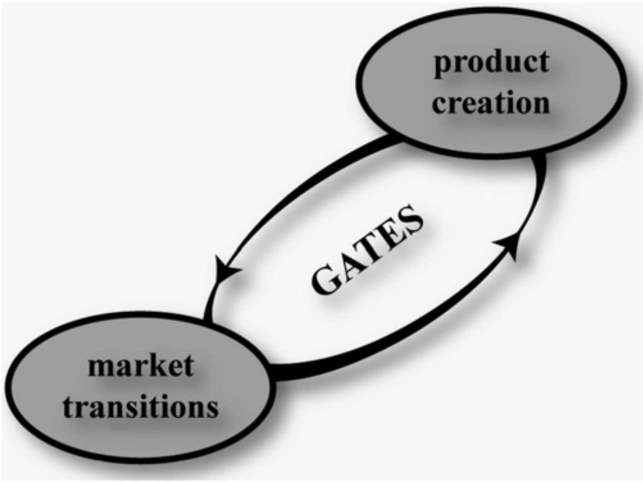

Fig. 3.6. Gates' cycle connects the product creation node with the market transitions node. Bill Gates, co-founder and former CEO of microsoft, is the role model for the cyclic interaction between products and markets. The combined feedforward and feedback loop is called Gates' Cycle.

Windows Vista on an Intel quad-core Xenon processor. Second, it guarantees the continuity of platform support and compatibility. Modern society would probably (albeit temporarily) collapse if Windows, Word, Excel and PowerPoint ceased to exist. And third, there is Bill Gates' impact on society which extends beyond his market dominance. Since 1995, Bill Gates has been #1 in the Forbes list of 'The World's Richest People', which means that he is the wealthiest person on the planet. Together with his wife Melinda, he created the Bill & Melinda Gates Foundation, which since 2000 has donated more $29 billion to charities (Gates, 2006). For all these reasons, Bill Gates is the prototypical role model for the interaction between products and markets. Fig. 3.6 shows Gates' Cycle in CIM.

3.4. The Soft Sciences Cycle (Schumpeter's Cycle)

The soft sciences cycle is located at the lower-left in CIM, and connects the market transitions node with the scientific exploration node. The market transitions node might be named after Wal-Mart, the largest private employer in the United States and the largest retailing company in the world (revenue of $316 billion and 1.8 million employees in 2006), which was founded in 1962 by Sam Walton. Wal-Mart's business model is based on selling a wide variety of general merchandise at 'always low prices'. The company focuses on selling more popular products, often dropping unpopular products in favor of more popular ones, and demands that manufacturers supply more popular products (Wal-Mart, 2006). Wal-Mart is the world's second largest corporation, behind Exxon Mobil.

The scientific exploration node might be named after Ludwig Josef Johann Wittgenstein (1889–1951), the Austrian philosopher who is widely regarded as one of the most influential philosophers of the twentieth century. He contributed several ground-breaking works to contemporary philosophy, primarily on the foundations of logic, the philosophy of mathematics, the philosophy of language and the philosophy of mind (Wittgenstein, 2006a). Even though his work has influenced society (albeit on a rather high conceptual level), Wittgenstein never anticipated the (practical) application of his scientific theories. In that respect, Wittgenstein may be considered 'the Einstein of the social sciences'. In CIM, his work in the soft sciences merges with the hard sciences, to establish the scientific exploration node as the combination of hard and soft sciences. One of the theses in his *Tractatus Logico-Philosophicus*, is gratefully embraced in this chapter (especially in Section 3.5, where the four nodes and their interacting cycles are combined into the full-fledged CIM): "The world consists of independent atomic facts – existing states of affairs – out of which larger facts are built" (Wittgenstein, 1921).

The two-way interaction between the market transitions node and the (soft) scientific exploration node is represented by the soft sciences cycle, which we named after Joseph Alois Schumpeter (1883–1950), the Austrian economist and influential political scientist, most famous for his theory of business cycles (Schumpeter, 1934, 1939) and his contributions to the theory of entrepreneurship. Schumpeter presented two theories (Mark I and Mark II). Mark I states that entrepreneurs are the driving forces behind innovation and technological change of a country (Schumpeter, 1942). The Lisbon Strategy (the European Union's development plan to stimulate innovation in Europe) is largely based on Schumpeter's ideas.

Schumpeter may be considered the social sciences equivalent of Pasteur, in that he plays an essential role in the two-way interaction between the (social) sciences and the markets (which may be considered as applied social science). Fig. 3.7 shows Schumpeter's Cycle in CIM.

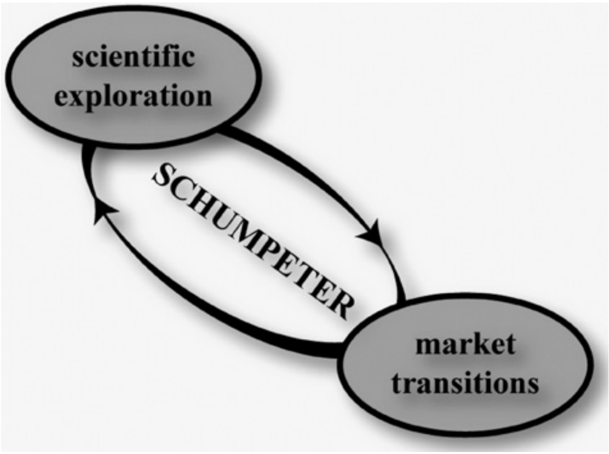

Fig. 3.7. Schumpeter's cycle connects the market transitions node with the scientific exploration node. The role model for the cyclic interaction between market transitions and scientific exploration is Joseph Schumpeter, who showed that entrepreneurs are the driving forces behind innovation and technological change of a country. The combined feedforward and feedback loop is called Schumpeter's Cycle

3.5. Combining the Four Basic Cycles into CIM

When combining the four basic interacting cycles into the complete CIM, we maintain the names describing the cycles (described in Sections 3.1–3.4), but revert to the generic names of the four nodes (scientific exploration, technological research, product creation, market transitions). The reason is that in the description of the individual cycles, each node obtained a double identity. For example, the technological research node interacting with the science node was labeled Tesla. But that same node interacting with the product creation node was labeled PARC. Even though a single role model for each of the four nodes might seem the natural choice, we feel that each node really turns a fundamentally different face towards each of the two interacting nodes. There is a subtle (albeit essential) difference between Nikola Tesla and PARC. Tesla was an engineer with solid (fundamental) scientific roots. PARC was an R&D lab with a commercial (product creation) endeavor. It is pointless to try and blend Nikola Tesla with PARC – either by choosing the most appropriate of the two, or by trying to find a third champion who combines both role models.

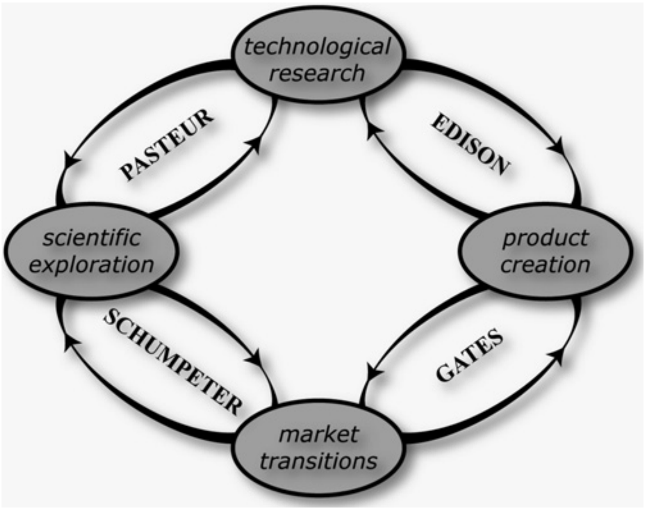

Fig. 3.8. The four fundamental cycles are combined into the cyclic innovation model (CIM). The names of the role models for each cycle illustrate the type of interaction between each pair of nodes. It triggers the imagination and makes it easier to refer to a particular cycle in CIM. Instead of 'The Integrated Engineering Cycle' or 'The Cycle Situated at the Top-right', we will henceforth refer to 'Edison's Cycle'.

Fig. 3.8 shows the combination of the four fundamental cycles in CIM. The names of the cycles are maintained, as they unambiguously convey the interactive nature of the arenas at the interfaces of the four CIM nodes.

4. THE DECOUPLING OF TECHNOLOGY AND MARKETS

There is a natural tendency to separate the Cyclic Innovation Model into two parts (see Chapter 2). Many national economies have experienced a cut between the top half of CIM (representing the leading question 'what is technically possible?'), and the bottom half (representing the question 'what is socially desirable?'). In our endeavor to attach names of prototypical role models to the individual parts of CIM, it is tempting to also find appropriate names for the top half (Science–Technology–Products) and bottom half (Products–Markets–Science) of CIM. However, it is important to realize that it is already a remarkable achievement to be a champion in a single interacting cycle between two fundamental nodes. The names we attached to the four basic cycles in CIM belong to the biggest heroes in their associated disciplines. It is therefore quite unrealistic to find even bigger names to represent two of these cycles simultaneously. There simply exists no role model who unifies the talents of Louis Pasteur and Thomas Edison. Similarly, we cannot expect to find anyone who combines the skills of Bill Gates and Joseph Schumpeter. Hence, we refrain from carrying through the labeling process too far. Likewise, it is impossible to find a role model for the full circle of innovation, even though it is tempting to cast Leonardo di ser Piero da Vinci (1452–1519), the Italian architect, anatomist, sculptor, engineer, inventor, mathematician, musician and painter.

The immediate consequence of the observation that, at best, the knowledge and skills relevant to two individual CIM nodes can be found united in a single person, is that collaboration between the cycles is crucial to the success of innovation. Only through teamwork (i.e., collaborations in networks of actors from each of the four fundamental CIM cycles) can true innovation take place. There exists no Leonardo da Vinci of innovation.

5. THE DUAL NATURE OF THE CIM NODES

The labeling of the four fundamental nodes of CIM, which was systematically carried out in Sections 3.1–3.4, showed an interesting, yet thus-far unmentioned phenomenon. Each node takes part in two different cycles, and as such each node exhibits a different character. More colloquially, one might say that each node shows a different face toward its neighbors nodes. This is most prominent in the scientific exploration node, where the role mode facing the technological research node (Einstein) is a fundamentally different scientist than the role model facing the market transitions node (Wittgenstein). In essence, each node is two-faced, and as such each node has two role models. Even though we do not place strong emphasis on the role models for the nodes – the role models for the cycles that are much more important – it does illustrate a fundamental aspect of CIM, namely that each node has a dual character. Fig. 3.9 illustrates this duality of the four nodes, with each node being labeled with two different names of the role models (see Sections 3.1–3.4).

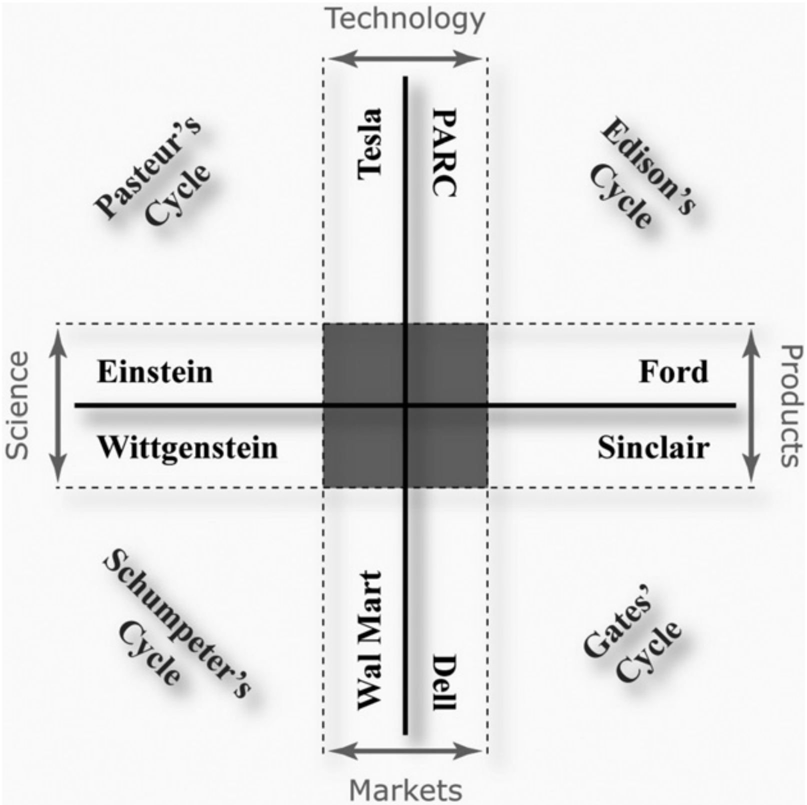

Fig. 3.9. Role models (Champions) in the four nodes and cycles of the cyclic innovation model (CIM). Note the duality of the nodes: each node shows a different face toward its neighboring nodes.

6. LABELING AS A VALIDATION MECHANISM FOR CIM

Attaching the names of undisputed champions to the fundamental nodes and cycles of CIM is more than merely dressing up CIM with familiar role models. It also serves as a validation tool which operates according to the pigeonhole principle (Grimaldi, 1998). This can be illustrated by analogy of an office where the incoming mail is distributed over a stack of mailboxes (pigeonholes). There should be a one-to-one correspondence between the mailboxes and the employees.

From an outside-in perspective, every mailbox should correspond to an employee. A mailbox that is always empty points to a potential problem in the organization. Likewise, an empty node or a void cycle in CIM indicates a problem. For if no suitable role model can be found to label a node or a cycle, the validity (raison d'être) of that node or cycle must be questioned. Also, the amount of incoming mail in a pigeonhole might be regarded as an indication of the importance of the employee to which the pigeonhole belongs.

Vice versa, the inside-out perspective requires that every employee has a mailbox. Incoming mail addressed to someone who has no pigeonhole, points to a potential problem. Likewise, the inability to find a suitable node or cycle in CIM to house a key player in innovation, indicates a potential shortcoming of the innovation model.

In essence, that is how the dilemma of the apparent schism between fundamental science and applied research was resolved by Stokes. He identified Louis Pasteur as a key player that could not be placed in the one-dimensional 'model', which suggested that the model was flawed. Similarly, the inability to place in CIM key players in innovation, would indicate that this innovation model is incomplete.

Of course, there are people and organizations that are difficult or even impossible to position in CIM, but that is because they play no role in the (technology-based) innovation arena; it is not a shortcoming of CIM. Examples are the Pope, Vincent van Gogh, Wolfgang Amadeus Mozart, or the United Nations. CIM is an innovation model, and in that capacity – connecting science, technology, products and markets – the examples given lie outside that arena. However, the basic concepts of CIM, particularly the cyclic interaction between fundamental actors (the nodes), can be adapted and applied to other disciplines, such as religion, art and politics.

7. CONCLUSIONS

We have labeled the nodes and the interacting cycles between the nodes of the Cyclic Innovation Model (CIM). It clarifies the various components of the model by attaching the name of a prototypical role model to each. It also validates the completeness of the model by means of the pigeonhole principle. Following the insight of Stokes that the scientific achievements of Louis Pasteur do not fit within the confines of the traditional one-dimensional spectrum that extends from fundamental science to applied research, we used CIM to extend the concept of the two-dimensional division into four quadrants. We slightly modified Stokes' concept by discarding the least interesting quadrant (which Stokes did not even name), and presented it in the framework of CIM. Next, we applied the same principle to the other three basic cycles of CIM. In this way, the four cyclically interacting loops comprising CIM were tagged with the names of prototypical role models for the two nodes and the interacting cycle between the nodes. After assembling the four cycles into the full CIM, we maintain only the names of the four basic cycles: Pasteur, Edison, Gates, and Schumpeter.

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PART II:
INTERACTIONS WITH OTHER SCIENTIFIC AREAS

CHAPTER 4

INNOVATION TAKES TIME: THE ROLE OF FUTURES RESEARCH IN CIM

ABSTRACT

The duration of an innovation process, from new idea to new business, may take many years. This makes it necessary to incorporate a vision of the future. The Cyclic Innovation Model (CIM) shows that aspects such as multiplicity (looking at multi-fold futures) and multidimensionality (looking at different aspects of the future) should be taken into account. Looking at the different actors involved in CIM, the future should be researched with an open mind (meaning that the transition path to the future should be kept wide open) and different time horizons should be taken into account.

1. LINKING INNOVATION TO THE FUTURE

This chapter describes how futures research can be carried out in the Cyclic Innovation Model (CIM). The future is an essential part of CIM. Fig. 2.1 in Chapter 2 illustrates that a view on the future functions as a kind of

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Leitmotiv for the innovation process and the transition path. The outcomes of the innovation processes together form the building blocks of the transition path toward that envisioned future. Since Fig. 2.1 only presents a general framework we want in this chapter to address more precisely how futures research (as we will call it) can be used within CIM.

First, we describe how the innovation process is related to 'the' future (Section 1). Then we will discuss more specifically what we mean by looking to the future by introducing the term 'futures research' and describing shortly its historical development (Section 2). After that, we will describe how futures research deals with certain issues when the future aspects of CIM are taken into account (Section 3).

Innovation takes time, often more than we expected or wished for. Between the first idea for an innovation and its market introduction later often many years pass. Even in the present, where many scientists, managers and entrepreneurs emphasize the need for decreasing the time-to-market, innovations are (still) not developed overnight. Of course, the total *innovation-time* differs per type of innovation. A Class 1 innovation (such as a new version of a piece of software) will not take much time to develop, but Class 4 innovations such as new cars or new medicines might take years, some even decades.

Between the first idea for an innovation and its ultimate market introduction many changes happen. During the development time, for instance, a new and competing technology can be developed, market needs change, and/or new societal developments can be initiated. All these changes make it difficult to foresee or to predict the chances of success of an idea for innovation. The future is often uncertain and a 'good' idea for an innovation might turn out to be a very bad idea later that leads to a failed market introduction: "During the period the new product is under development market needs may change or they may be satisfied by a competitive product or an innovation based upon a different, and perhaps superior, technological concept" (Twiss, 1992). Again, a current idea for an innovation not necessarily has to be a successful innovation at a future date when it is introduced to a market: "Nowadays, technical lead times are often so long that a market can be lost before a proper response is made" (*idem*.).

Collingridge (1980) views the lead time of an innovation in terms of the 'dilemma of control'. This dilemma states that "the social consequences of technology cannot be predicted early in the life of the technology. By the time undesirable consequences are discovered, however, the technology is often so much part of the whole economic and social fabric that its control is extremely difficult" (*ibid*., p. 11). Collingridge does not believe that the course of technology or innovation can be changed during its lead-time, and he is skeptical of assessing its future (social) consequences. He claims that it can be valuable to diversify technological developments to cope with this dilemma. Collingridge's dilemma illustrates that between the stage of first getting a technological idea and implementing it later on various changes may well occur. Indeed, such dynamism inevitably necessitates much innovation process adjustment. If the future is, in fact, anticipated that will decrease the number of adjustments that need to be made while increasing the effectiveness of the innovation process. Development costs and risks will thus be reduced.

So, not surprisingly, many authors relate innovation processes to future developments, and sometimes they even consider attention to the future to be crucial to an innovation (e.g., Twiss, 1992; van Lente, 1993; van der Duin, 2006). Preez and Pistorius (1999) state that: "One of the major challenges in the management of innovation […] becomes one of managing the technological future" (p. 215). Cooper (1980) found that the innovator's knowledge and intuition about future market developments is the second most important factor explaining the viability of innovation projects. Cobbenhagen, Hertog, and Pennings (1994) showed that in the 1990s successful innovating companies had put topics on their business agenda that would become important for innovation five years before their less successful competitors. Furthermore, Johannessen, Olaisen, and Olsen (1999) state that in the knowledge economy the innovation-led company must be able "to visualize or identify pictures of future opportunities and turn them into reality, as well as a sense of optimism and faith in the future" (p. 18).

Concluding, during the innovation process there are many uncertainties (which may be of a technical, regulatory or commercial nature). The kinds of questions going through an innovator's mind may be these: when our product is placed on the market will it actually be needed? Is the whole idea technologically feasible? Will the innovating company be able to provide the technological knowledge required to make the idea work?

When in innovation processes the future is taken into account, companies are able to recognize and ultimately cope with such uncertainty. This means that they, looking to the future, should result in providing an overview and assessing the effects that certain developments (might) have on innovation processes.

Although looking to the future is considered to be important for each innovation process, the question remains how to use futures research in innovation processes. More precisely, how can *futures research* (see Section 2) be used in CIM? In this chapter we will attempt to answer this question.

2. FUTURES RESEARCH: DEFINITION AND A HISTORICAL OVERVIEW

2.1. Definition

The 'future' is a very important concept in innovation processes. But how to look to the future? What is looking to the future?

The 'art of looking at the future' has been given many different names (in different phases of its development),[1] each of them emphasizing different aspects of futures research. Futures researchers such as Dutch futurologist Fred Polak (1971), Eleonora Masini (1993), Pentti Malaska (2001), and Job Fowles (1978) all suggest different names, such as futurology, futurism, conjecture, forecasting, prospectivism, prognostics, futures studies, futures study, prospective study, futures research, and long-range planning. After a careful review of the terms, we have decided to use the term *futures research* because:

1. *Multiplicity*: the term *futures* refers to thinking in multiple futures (instead of just one), which is very common nowadays or even dominant in studies of the future.
2. *Multidimensionality*: the term *futures* also suggests that possible futures are considered from social, cultural, economical, political, and technological perspectives.
3. *Research*: the term research implies that no a priori standpoint is taken about whether the future can be controlled, constructed or explored. It emphasizes that the future can be investigated and coped with, and that knowledge about the future can be gained which can serve as a valuable contribution to today's decisions for the future.

Based on this we provide the following definition of futures research: Futures research is the ability, the competence and the art of describing, explaining, predicting, exploring and/or interpreting future developments as well as its consequences for actions and decisions in the present.

Equal to the amount of different terms used for futures research, many different types of futures researchers can be distinguished. Some futures researchers pay more attention to predicting the future, while others have more knowledge about the process of carrying out futures research. Futures researchers can be placed in any node of CIM. The more 'traditional' futurists are mainly located in technological research node, the market forecasters are mainly in the product creation and market transitions node, and those who are mainly involved with futures research from a scientific perspective are in the scientific exploration node.

Futures research should be clearly distinguished from market research (Chapter 5). Although market research often yields predictions about the future and can be used in innovation processes (mostly in the implementation phase, i.e., the last phase of the innovation process), it is more oriented toward researching current and, sometimes, near future situations and developments. Also, it often focuses on a single aspect, for instance the current adoption of a specific product within a specific market segment. Futures research, however, has a more distant time horizon and also a broader scope, taking into account economic, social, technological and political developments. Another difference is that market research (and its methods) mainly uses existing variables, whereas futures research is aimed more at exploring possible new variables and possible new relationships between new (and existing) variables.

2.2. Historical Overview of Futures Research

The modern history (starting after World War II) of futures research reflects a transition from a hard, isolated, and conscious set of activities and methods of technology forecasting in the 1950s and 1960s, to a softer, integrated and communicating process of futures research from the 1970s onwards (van der Duin, 2006). Initially, futures research was conducted mainly for national governments, with an emphasis on predicting and controlling the societal environment resulting from the rapid increase of technological and economic developments. It is not surprising that ‘technological forecasting’ (or ‘technology forecasting’) was the most frequently used term for looking to the future in the 1950s and 1960s. Other influences came from developments in fields such as operations research and mathematics that gave futures research a highly quantitative and predictive character. Currently, firms are important clients of futures research which often has a global focus and is aimed at exploring both the environment and the future. There is an awareness of the limits to growth of technology and economy that is increasingly influencing the ‘span of control’ of organizations. Futures research has become a separate discipline with its own organizations, practitioners, journals, and books. Rescher (1998) mentions the rise of a distinctive movement of futures research, even leading to an industry of ‘futurism’. Futures research is to a great extent integrated with other academic disciplines and with other parts of organizations, thereby combining different methods, using (new) software tools, using new ways of gathering data, and applying different creative techniques. This contrasts sharply with the 1950s and 1960s when futures research was primarily the domain of experts ('futurists'), who used complex and quantitative models to deploy long-term predictions. This does not, however, mean that predictive methods are not used anymore. Indeed, the portfolio of methods of futures research has been supplemented by more exploratory methods. Both types of methods can be complementary and are often seen in combination (Masini, 2002; Bouwman & van der Duin, 2003). The development of new methods of futures research has become more focused on capturing and describing possible future developments and variables, instead of choosing a few variables and trying to forecast the future course of these variables.

It seems that developments in futures research also keep in step with economic developments. In other words, an increase in economic growth is accompanied by a growth of interest and activity with regard to futures research. A historical overview shows that the 1950s, 1960s, and 1990s were prosperous times for futures research while economic growth in those decades was also positive. The 1970s and 1980s were bad times for futures research, in terms of the amount of interest and activity. In fact, those decades reflected bad economic times as well. An explanation for this relationship might be that a positive economic climate gives people and organizations the time and money to look forward, and makes them optimistic, whereas a bad economic climate shortens the time-horizon of people and organizations, thereby reinforcing economist J.M. Keynes' famous phrase: "In the long run we are all dead".

The historical development of futures research is in line with the historical development of innovation processes (see Chapter 1). The four generations of innovation management are paralleled by the historical development of futures research.

Table 4.1 indicates that developments in both disciplines take place in (roughly) the same period. Considering the contextual description of the

Table 4.1. Generations of Innovation Processes and Futures Research.

	Innovation Processes	Futures Research
Generation 1: 1950–1960	Technology push	Technology forecasting
Generation 2: 1960–1970	Market pull	Technology assessment
Generation 3: 1970–1980	Coupled innovation processes	Explorative futures research
Generation 4: 1980 – present	Innovation in systems or networks	Networked or systemic futures research

historical development of futures research, we cannot automatically claim that the development of innovation management steers the development of futures research. This is very difficult to determine and engaging in a discussion about which development is dominant is not very fruitful. Much more interesting and practical is to state that the historical development of both disciplines (innovation management and futures research) suggests that there should be a balance between both. That is, an innovation process based on technology push is best accompanied by a technology forecast. A technology forecast provides the most relevant information to this type of innovation process rather than a study of the future based on a technology assessment (which includes also societal developments). For a technology push type of innovation process, the main emphasis is on assessing how technology developments are evolving and receiving information about markets or society as provided by a technology assessment will be considered not or less relevant or too early since the technology is the only thing one is taking into consideration (so far).

We claim that to properly implement studies of the future in innovation processes the basics of both must be of the same generation (see also, Gerybadze, 1994). Given that currently fourth generation of innovation processes are more and more used, it is interesting to see how fourth generation futures research can be aligned with a fourth generation innovation model such as CIM.

3. LINKING FUTURES RESEARCH WITH CIM

Given the (historical) connection between innovation and futures research, the next step is to investigate how futures research matches with CIM. We do this by using the three elements of our definition of futures research in Section 2 (multiplicity, multidimensionality and research) and the concept of time horizon.

3.1. Multiplicity

Innovation processes are inherently uncertain. Although actors involved in the innovation process can do much to reduce this uncertainty, one can never be entirely certain that an innovation will be developed successfully. After all, if you can predict it, it will be probably not an innovation … . That is, given that each innovation has a certain amount of newness, certain aspects of it will be very difficult to predict and, therefore, carries uncertainty. CIM acknowledges that innovation processes are uncertain. The comprehensive nature of CIM in terms of, for instance, the large number of different actors involved in the innovation process, is a clear source of uncertainty because all these actors will have different wishes, demands, capabilities, knowledge, and interests that will change over time and that will influence each other. These differences, their change and the way they interact are difficult to describe and to predict causing (again) uncertainty.

Given this uncertainty, with regard to the use of futures research within CIM, it should be clear that predicting the future is difficult when CIM is applied. After all, a prediction assumes a rather certain future. So, it is wiser to explore the future and to have different images of possible future worlds. A more exploring approach to the future which addresses the multiplicity of 'the' future is very much in line with CIM. This does not has to mean, however, that CIM has to deal with multiple futures. Of course, different actors in CIM will hold different images of the future but it is important that somehow all actors share a common view on the future (the 'view of the future' in Fig. 2.1). This single image of the future should not be considered as a prediction but as a kind of *Leitmotiv* (see also Section 1 of this chapter). It does not have to be a problem if some actors in CIM hold more than just one view for the future (on the contrary), but the common image of the future should be one of those. Therefore, in establishing this common image all actors should be involved thereby making it a kind of democratic process to the extent that actors hold different views on the future as well this should be made explicit and communicated to all other actors. In doing this a 'strategic conversation' (van der Heijden, 1996) might arise strengthening the communication and interaction between the different actors with regard to the future.

3.2. Multidimensionality

CIM views the innovation process as a combination of many different expertise, flows of knowledge, and relationships between different actors who all contribute to the innovation process. True innovations do not arise from minor adjustments to one aspect of an existing product or service, but only when there is a significant change in different nodes of CIM. The development of an innovation is fed by inputs from different fields such as technology, economy and society.

This integral nature of CIM should be reflected in futures research. It is no longer sufficient to focus a study about the future used in an innovation process on only one topic. When used in CIM, studies of the future should incorporate different topics so that the innovation process is supported with information on different topics. Just a technology forecast or only an assessment of market developments is insufficient for carrying out innovation with the support of CIM. The different actors within CIM can be considered to represent these different aspects of innovation and by that the different aspect of the future as well. All should be given the chance to express their view on future development in their specific domain (science, technology, product, and market/society).

To address this multidimensionality, CIM can be supplemented with a tool such as a DESTEP-analysis. DESTEP is the acronym for: demographics, evironment, social, technology, economy and politics. To ensure that the study of the future is sufficiently comprehensive, it must take into account developments in all these fields. The six fields also apply to most CIM cycles:

- The hard sciences cycle: technology
- The integrated engineering cycle: technology, economy
- The differentiated valorization cycle: economy, social
- The soft sciences cycle: social, politics, environment, demographics

Indeed, science is missing in the DESTEP-analysis and, therefore, is a valuable addition to it. The degree of multidimensionality, however, can differ depending on the type of innovation that is developed. A Class 4 innovation means that changes are needed in all the four nodes of CIM and the futures study should definitely address future developments in those four nodes. A Class 1 innovation means that only a change in one of the four nodes and, therefore, it is not necessary that the future takes into account developments in all four nodes.

Multidimensionality does not only mean taking as much as possible topics into account when doing futures research but to think about how these different developments influence each other as well. Exchanging information and opinions about the future between actors is one thing but together thinking about what certain developments in one node or domain means for actions, decisions and developments in other domain is perhaps more important. By doing this not only an overview of future developments is constructed but their relationships as well leading to a kind of 'integral futures'. It can be assumed that this integral future conveys more and better information and knowledge about the future than just an overview of future developments because the conditionality of each future development is being assessed. That is, it may turn out that a certain future development in a node is less certain than initially assumed because it is influenced and perhaps even dependent on a future development in an other domain. Different future developments in different nodes together form a kind of 'causal circle' in which these developments influence each other. This is a complex system causing in itself *uncertainty* because it is difficult for actors to grasp. So, not only the nature of future developments causes uncertainty, but the framework (or system) to describe and address all these future developments as well. We think that the best way to cope with all this is to increase communication and openness about the future among the actors, to think in multiple futures, and, at the same time, to have a common view of the future, regardless whether this future ultimately turns out to be the most accurate one. The main function of the future within CIM is to inspire actors and show their interdependency.

3.3. Research

Because innovation processes are uncertain, some people believe that innovation processes cannot be managed, and are only the result of luck and serendipity. However, innovation is too important for organizations and national economies to completely ignore it (Tidd, Bessant, & Pavitt, 2001). Also, several studies have shown that there are indeed some best practices that organizations can apply to improve their innovation processes (van der Panne, Beers, & Kleinknecht, 2004). CIM in particular is an innovation model that is aimed at describing and prescribing the innovation process thereby being a means for actors to manage their innovation process.

A bit the same holds for looking to the future. Because of the disappointment caused by failed predictions and false expectations of the future in the past, many people and organizations have developed a kind of fatalistic attitude toward the future: "the future cannot be predicted so why bother thinking about it?" However, one can take a more explorative approach toward the future. That is, one can think about what *might* happen in the future instead of trying to determine what *will* happen in the future (i.e., predicting or forecasting), which is indeed often very difficult to realize.

So, CIM and futures research hold the same active attitude. They both recognize the inherent uncertain nature of the innovation process and of the future, but they oppose the idea that nothing can be done about it. In both cases, actors can try to influence and manage the innovation processes or they can collect more information and knowledge about (possible) future developments. Not by making very detailed predictions but by sketching different possible images of the future. Researching the future means that the innovators (and the futures researchers) are sincerely interested in the future and are curious about how to connect the future with the innovation they are busy developing.

3.4. Different Time Horizons

Futures research can be applied both to the short-term and long-term. We see a time horizon not as an absolute unit but a relative unit. One decade from now might be short-term for an oil-company, but it is a long-term prospect for a software producer. For a company, the time-horizon will often be shorter than for a government organization because the market situation often changes very quickly thus resulting in a short(-er) time-horizon and political and societal changes are most of the time less dynamic. So, deciding whether a specific time horizon is short-term or long-term will depend on the dynamics of the business environment of a company. The length of the time horizon is also reflected in the length of the innovation process. In dynamic industries, such as fast moving consumer goods, innovation processes tend to be short and vice versa. In industries in which technological platforms and infrastructures are important, such as the oil-industry, the technology life cycles and (thus) the innovation processes are longer.

Within CIM different actors are involved in developing an innovation. This means that different time-horizons will be present because the actors are active in different industries or segments of society. Scientific research is carried out mainly at universities and the process of obtaining new scientific knowledge often takes a long time. Organizations involved in product creation (mainly companies) need less time to develop new products. Differences in time horizons can cause problems in the innovation process because actors have different deadlines for their innovation activities. For example, if through the differentiated valorization cycle it becomes clear that customer needs are changing rather quickly, it will not be easy for the integrated engineering cycle to develop (instantly) the new knowledge required at the same rate since the dynamics of that cycle are lower. In general, this means that differences in time horizons of both actors and cycles can make the whole innovation process less efficient (i.e., more time is needed for the innovation process) and less effective (i.e., wrong knowledge might be developed because of the delay of incentives that is communicated through the cycles). A timely sharing of possible new future developments is then very important because it gives each actor more time to adjust and to respond to new wishes and demands from other actors.

It can be argued that the time needed to develop an innovation differs per type of innovation. A Class 1 innovation, which entails a change in only one node of CIM, often takes less time to develop than a Class 4 innovation that needs a change in four nodes of CIM. A Class 4 innovation means that in every node of CIM new knowledge has to be developed and that will take more time than a Class 1 innovation. Given the difference in time horizon between the actors, this will be less of a problem with a Class 1 innovation because in that case only one actor is involved in the innovation process. And this will be a bigger problem in developing a Class 4 innovation since many actors with different time horizons will be involved.

A closer look at the time horizons shows another element that is related to the different time-horizons in CIM. Given that the dynamics within a node of CIM are often not dissimilar (and, subsequently, the time horizons), actors will also find it difficult to anticipate on future activities of other actors in CIM. That is, an actor not only needs to take into account what another actor is doing at present, but the actor must also try to imagine what the actor might do in the future. Fig. 4.1 shows this by illustrating CIM three-dimensionally. An actor in the scientific node does not only look at current activities of an actor in the technology development node ($t=0$), but the actor will also need to look at what this actor might do at $t=2$.

Results from scientific research will probably be applied within the technological research node in another time-frame. The time needed to translate knowledge from, for instance, space-research into technological developments (i.e., the hard sciences cycle) is different from the time needed for the soft sciences cycle to translate that knowledge. Van Oirschot (2003) describes this time dimension problem in another way by addressing the different 'time to–' approaches. For instance, the *time-to-market* can be used to describe the total time needed to put a new product on the market, measured from the moment of a potential market need until the moment the need is fulfilled by the innovation, and can thus be applied to the customized service and system engineering cycles. And the *time-to-knowledge* describes the time needed to develop new competences due to new market and scientific insights.

But how to cope with this difference in the length of time horizon between the actors in CIM? One solution might be to solve it by determining a kind

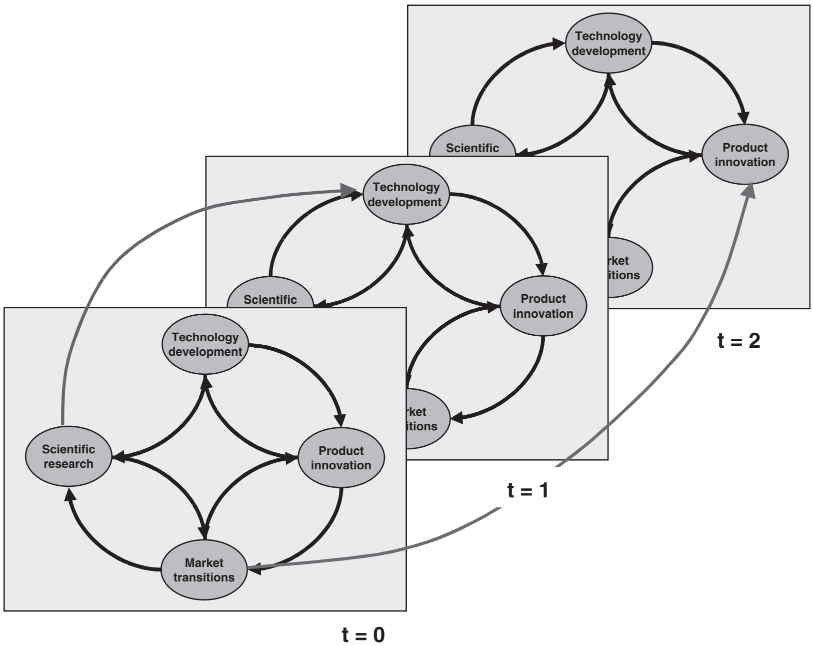

Fig. 4.1. Different time horizons in CIM.

of 'average time horizon'. This means that besides its 'own' time horizon, every actor in the innovation process must also operate in line with this average of overall time horizon. It can be assumed that this time horizon will be the time horizon that is the most far away from the present. However, because of the needed close working relationships in CIM, actors with the longest time horizon will also receive an incentive to shorten their time horizon and to speed up their activities because actors with short time horizons will constantly ask them to do so. However, receiving information in an early stage (at least for the actor with a long time horizon) means also increasing the ability to anticipate on future developments, although that does not have to mean that they can speed up their work. But by receiving relevant information earlier they can start working in an earlier stage and be better on time. The actors with the shortest time horizon suffer the most from the problem of different time horizons because they have to wait until the actors with longer time horizons have finished their work. Overall, the entrepreneur can fulfill a coordinating role in aligning the time horizons in CIM. The entrepreneur has an overview of all activities in CIM and is capable of quickly contacting an actor if he or she sees a change in another node. In this sense, the creative entrepreneur acts as a kind of 'early warning system' within CIM.

To conclude, a direct consequence of an innovation process that consists of many actors (as modeled by CIM) is that the study of the future that accompanies the innovation process should be carried out by the same actors that are involved in the innovation process. This 'networked innovation process' should be mirrored by a kind of 'networked futures research'. Futures researchers of different actors (companies) should cooperate and share not only methods and practices of futures research, but data and information as well. The future study should be a joint activity. Nowadays companies share activities such as R&D, innovation, marketing and product sales with other companies, and each company contributes its core-competence. Futures research should also become a part of that portfolio of shared activities.

NOTE

1. Which has made Edward Cornish speak about 'a field in search of a name' (1978, p. 155).

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CHAPTER 5

MARKET ANALYSIS TO ASSESS THE POTENTIAL OF BREAKTHROUGH TECHNOLOGIES☆

ABSTRACT

The ability to predict the market potential of product concepts at an early stage is of great importance to many organizations. In terms of Cyclic Innovation Model (CIM), this activity occurs in the lower right part of the cycle. Standard approaches to predict the market potential like concept testing and need assessment, and the assumptions that are required to use these methods will be described in Section 2. A problem is that these assumptions are usually not met in the case of products based on breakthrough technologies. Alternative approaches will be described in Section 3. How market analysis can benefit from using CIM will be discussed in the last section.

1. INTRODUCTION

The Cyclic Innovation Model (CIM) is especially relevant for breakthrough technologies since the development and diffusion of these technologies

☆Co-authored by David Langley and Nico Pals

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pervade all processes of change, as will be illustrated below for the jet-engine. By distinguishing these processes, i.e., scientific exploration, technological research, product creation and market transition, CIM clarifies where market analysis should focus on to predict the potential of breakthrough technologies.

Breakthrough technologies represent either an advance in technology that is so significant that attainable price/performance ratios are altered dramatically or entirely new kinds of applications are possible (Tushman & Anderson, 1986). Examples of breakthroughs that shifted price/performance ratios are the jet-engine (compared to internal combustion engines) dynamite (in comparison to nitro-glycerine) and strong fibres like Kevlar (in comparison to contemporary fibres like Nylon). Examples of breakthrough technologies that enabled entirely new applications at the time of their invention are radar technology, laser technology and communication technologies like telegraphy, telephony and television. The case of the jet-engine will serve as an illustration how a breakthrough technology can have an impact on all four processes of change and how this interferes with assessing the market potential of this technology.

1.1. CIM and the Jet-Engine

The jet-engine was almost simultaneously developed in the late 1930s by Whittle in the United Kingdom (Golley, 1996) and Ohain in Germany (Kay, 2002). At that time, the means of propulsion, i.e., propellers powered by an internal combustion engine, could not enable speeds near the speed of sound. Whittle was an engineer and a pilot. During his studies, he developed the idea for this revolutionary new type of propulsion. Ohain, in the same period, and independently from Whittle, graduated in Germany as a physicist on the principle of the jet-engine. In both cases, the idea for the invention was based on scientific explorations. This idea, however, required materials that could withstand the temperatures and pressures inside the jet-engine. As these materials were not available, scientific exploration was required again. Whittle started to experiment with prototypes of the jet-engine on the premises of a factory that developed these types of materials. So, the technological research and scientific explorations were interlinked by feed forward and feed backward loops. After some years of disappointing results and a lack of resources, finally a working prototype of the engine could be mounted on an airplane. Product development efforts focussed on adapting airplanes to the jet-engine, while technological research focussed on improving the performance and reliability of the jet-engine and adapting it to the use in an airplane. Again, mechanisms of feed forward and backward characterize these efforts but this time between product development and technological research.

In the late 1930s, the UK as a society had a notorious anti-war attitude, although at the same time, the government recognized that the threat of the growing German military system required a prompt response. It was of utmost importance to replace old-fashioned double-winged airplanes by modern spitfires (a full metal, propeller-powered airplane), yet the funding for this major operation was hard to find. In these circumstances, the jet-engine, which could have altered the Second World War dramatically, was pushed aside as an impossible idea given the state of the contemporary materials. The market transitions at that time implied that almost no resources were available to develop jet-powered airplanes. After the Second World War, the introduction of the jet-engine changed the market for airplanes drastically. Rather than the complete substitution of propeller-driven airplanes, a new structure of the aviation market emerged. The relatively expensive jet-engine with its superior performance was first used for military aircraft and later on for large civilian airplanes. The emergence of the jet-engine caused large market transitions, first in military and later in civil aviation. These market transitions, in turn, changed the demand for the airplanes and required new product development efforts: civilian airplanes steadily increased in size and military airplanes steadily increased in performance. So, again, mechanisms of feed forward and feed backward between product development and market transitions can be seen.

In hindsight, it can be seen that the military forces and the governmental aviation agencies had problems in predicting the consequences of at least three separate processes of change. First, they were unable to predict the results of technological research on alternative systems of propulsion. At that time, gas turbines, improved turbo-powered internal combustion engines and jet-engines were competitive means of propulsion for airplanes. Since these technologies were in different stages of their technology life cycle, it was hard to derive their market potential just by comparing their performance at one point in time. Second, they were unable to predict the results of scientific explorations on new materials able to withstand the temperatures and pressures in the jet. Third, they were unable to predict the market transitions that would result from the diffusion of the jet-engine. In addition to these issues, political interests interfered with the ability to predict. Research funding for the alternative technologies was determined by scientists in government agencies. These agencies, in CIM-terms, performed the central entrepreneurial and coordination role. However, these scientists also had their own interests since they were also engaged in scientific explorations and technological research. One of the first very negative reports on the jet-engine, for example, was written by a scientist with an interest in an alternative system (Golley, 1996).

We conclude that CIM, by distinguishing separate processes of change, provides an overview that is needed to assess the (market) potential of breakthrough technologies. In the remainder of the chapter we will start with standard consumer research methods, their limitations to assess the market potential of breakthrough technologies and the alternative approaches to circumvent these limitations. We will show that CIM provides valuable guidelines and a proper perspective to focus market analysis in the case of breakthrough technologies.

2. CONSUMER RESEARCH WHEN BREAKTHROUGH TECHNOLOGIES ENTER THE MARKET

2.1. Concept Testing

In the early stages of a product development process, consumers' preferences regarding a product are often inferred from their evaluations of a concept. Concept testing refers to a variety of marketing research-based approaches employed to determine the degree of (potential) buyers' interest in the new product idea and to refine or improve the idea (Page & Rosenbaum, 1992). "The primary purpose of concept testing is to estimate consumer reactions to a product idea before committing substantial funds to it." (Moore, 1982, p. 279). It is described as a valuable consumer research technique in the early stages of the product development process (Crawford, 1991; de Bont, 1992; Greenhalgh, 1985; Moore, 1982; Wind, 1982). In practice, testing a concept is a procedure in which selected respondents (mostly a sample of potential consumers) are invited to evaluate the concept (a presentation of the product) based on a number of criteria. Instead of potential consumers it is also possible to invite experts to indicate consumers' preferences. Different types of concept tests and the general assumptions required for valid results are described in the first row of Table 5.1.

2.2. Need Assessment

Approaches to investigate needs that could be fulfilled by the new technology are described by several authors (Crawford, 1991; Engel, Blackwell, &

Table 5.1. Consumer Research Methods of Market Research.

Consumer Research Methods	Assumptions for Valid Results
Concept testing: focus on what the new product may offer the potential consumer • Testing consumer opinions and preferences to new products as opposed to current products in the market • Conjoint measurement is a method that assesses the most important product attributes by comparing alternative attributes. Method determines the relative evaluation of new and current products (combination of attributes) • Observation studies of the use of a prototype of a new product by potential consumers • Testing consumer opinions and preferences to a computer simulation of a new product • Testing consumer opinions and preferences and use this to show the relative position of new and current products on important dimensions (e.g., multi-dimensional scaling)	1 No unexpected groups of potential consumers emerge 2 Usage situations and behaviours relating to the new product are not significantly different from existing products 3 No new needs emerge that cannot be derived from current behaviours or problems and complaints regarding current products 4 Consumers (or experts on their behalf) are able to articulate the future needs or rank pre-specified needs 5 There is a product (prototype, mock-up or description) available 6 Consumers (or experts on their behalf) can understand the product and its likely impact on daily lives 7 A new product does not comprise a completely new set of attributes 8 Evaluation requires no long-term learning process
Direct need assessment: focus on what the consumers say they need • Open questioning to assess needs in regard to a specific product category or in a specific usage situation • Ranking of a set of pre-specified needs	1 No unexpected groups of potential consumers emerge 2 Usage situations and behaviours relating to the new product are not significantly different from existing products 3 No new needs emerge that cannot be derived from current behaviours or problems and complaints regarding current products 4 Consumers (or experts on their behalf) are able to articulate the future needs or rank pre-specified needs
Indirect need assessment: focus on what the consumers may need even though they are unaware of this themselves • Making a problem inventory in regard to a specific product category and usage situation • Models to infer future needs from present patterns of behaviour (e.g., structured analogies) • Role playing	1 No unexpected groups of potential consumers emerge 2 Usage situations and behaviours relating to the new product are not significantly different from existing products 3 No new needs emerge that cannot be derived from current behaviours or problems and complaints regarding current products

Miniard, 1990; Holt, 1976; Holt, Geschka, & Peterlongo, 1984). Two approaches to assess needs will be distinguished: direct and indirect approaches. In a direct approach, respondents are asked whether they have any needs in a specific situation or in regard to a particular product category. In an indirect approach consumers' experiences with currently available products (belonging to the same category as the innovation) or consumers' experiences in specific situations (in which the innovation can be used) can be investigated to infer unrecognized or latent needs. There are several methods to infer needs (Holt et al., 1984) like problem inventories (Fornell & Menko, 1981) or advanced models to infer needs from current behavioural patterns (examples in the field of telecommunication are provided by Noll, 1986; Noll & Woods, 1979; Curien & Gensollen, 1989). Need assessment approaches and the general assumptions required for valid results are described in the second and third rows of Table 5.1.

Concept testing is more specific than need assessment, as it indicates the type of product form that is preferred to fulfil a need by these consumers. From the table it can be seen that this extra information comes at a price: valid concept test results require that extra assumptions have to be met. Both direct and indirect need assessment rely on a subset of these assumptions.

An important question is whether these assumptions are met when breakthrough technologies enter the market. In some cases, like the transistor, these assumptions seem to be met. The Bell telephone company exploited telephone lines. The telephone signals were amplified using vacuum tubes. These tubes, however, often malfunctioned and in the case of long-range telephony, repairs were laborious and expensive. So, an existing market actor (the telephone company) had a well-defined need. The transistor represented a breakthrough because it was far more reliable. Similar examples of potential consumers with a well-defined need are provided by the case of dynamite (the need for an explosive that, unlike nitro-glycerine, only explodes when wanted) and radar technology (military forces want to detect air and sea traffic from a distance, at night or during fog). In fact, the need for these breakthrough technologies was so apparent that market research was not and efforts solely focused on the technological uncertainty. These technologies also have in common that multiple processes of change are controlled by a single organization. AT&T and the Bell labs (transistor), Nobel (dynamite) and the military forces (radar) controlled at least three out of four processes of change and thereby facilitated a smooth transition and proper mechanisms of feed backward and feed forward between the nodes of the CIM.

In some other cases, like memory metal, these assumptions were not met. Memory metal is a class of alloys that, after distortion, can take its previous shape when it is heated. Memory metal was discovered by chance and is a typical example of a breakthrough in search of a market application (Kauffman & Mayo, 1996). Market research was needed to indicate its market potential. Specific product forms, applications and potential customer groups were not known at that time. There was no specific product concept and it was, at the time of the discovery, not known what needs the breakthrough technology could fulfil. So, basic assumptions for concept testing and need assessment were not met.

When breakthrough technologies first enter the market, depending on the specific case, all, some, or none of the assumptions for valid concept test or need assessment results are fulfilled. Apparently, there is no general rule. In the next paragraph we will indicate what can be done to explore the market when one or more of the assumptions are not met.

3. WHAT CAN BE DONE WHEN ONE OR MORE OF THESE ASSUMPTIONS ARE NOT MET?

When breakthrough technologies are first introduced into the market some of the assumptions for valid concept test results may not be met. We will show that by adapting and combining methods or by developing new methods this problem can be overcome. The first approach is to adapt existing methods of consumer research. The second approach is to combine consumer research with market structure analysis or futures research. The third approach is to circumvent traditional market and futures research methods and use theoretic models. The fourth approach is to explore the market by actually introducing products in the market and subsequently learn from the market reactions and adapt the product accordingly. These approaches will be elaborated below.

3.1. Adapt Existing Consumer Research Methods

3.1.1. Strategy 1A: Adapted Concept Testing

Concept testing involves decisions regarding (a) the selection of respondents, (b) the presentation of the concept, and (c) the criteria by which respondents

Table 5.2. Assumptions that Have to be Met for Concept Testing.

1. No unexpected groups of potential consumers emerge
2. Usage situations and behaviours relating to the new product are not significantly different from existing products
3. No new needs emerge that cannot be derived from current behaviours or problems and complaints regarding current products
4. Consumers (or experts on their behalf) are able to articulate the future needs or rank pre-specified needs
5. There is a product (prototype, mock-up or description) available
6. Consumers (or experts on their behalf) can understand the product and its likely impact on daily lives....
7. A new product does not comprise a completely new set of attributes
8. Evaluation requires no long-term learning process

are asked to evaluate the concept (Klink & Athaide, 2006). If the assumptions 6–8 (see Table 5.2) for valid concept test results are not met, then adaptations are possible regarding these issues.

3.1.1.1. Adaptations in the Presentation of the Concept. When assumptions 6–8 are not met, virtual concepts may illustrate the basic working of the product and let the respondent practice how to use it. If the virtual concept also conveys a realistic (virtual) usage situation, the respondent can infer the impact of the product on his daily life. Virtual testing is described by Loosschilder (1998), Urban, Weinberg, and Hauser (1996) and Urban et al. (1997).

3.1.1.2. Adaptations in the Selection of Respondents. The selection of respondents for concept testing may help to meet assumptions 6–8. Alternative selections of potential consumers can be invited for concept testing (Ortt & Schoormans, 1993; Ortt, 1998; Schoormans, Ortt, & de Bont, 1995). One possibility is to select innovators with regard to the product category to which the innovation belongs. These innovators have prior knowledge regarding products from the same product category. Another possibility is to select respondents with prior knowledge of the usage situation in which the new product will be applied. The latter option is shown to be more important for the level of the evaluation. Both options are important for the validity of the evaluations. So, when a new telecommunication product is tested in the context of distant education it makes sense to select respondents with experience in distant education and to select respondents with prior knowledge of advanced telecommunication products and services.

3.1.1.3. Adaptations in the Evaluation Criteria. In the case of novel product concepts, respondents may not be able to evaluate the (relative) importance of the physical product attributes, nor can they indicate their intention to purchase. Answering these standard questions in a concept test requires that the working of the product and its benefits in daily life are understood. Alternative evaluation criteria are suggested in these cases, like the perceived innovation attributes (Holak, 1988; Holak & Lehman, 1990; Ostlund, 1974; Rogers, 2003; Tornatzky & Klein, 1982), combinations of liking and purchase intent or combinations of purchase chance and various other criteria like the intention to request additional information, to try the product or to hire the product (Ortt, 1998).

3.1.2. Strategy 1B: Need Assessment (Direct and Indirect)

Suppose that, after consideration of all possible adaptations in concept testing, assumptions 6–8 are still not met. In that case, need assessment is an alternative. Applying need assessment requires that assumptions 1–4 (for direct approaches) or 1–3 (for indirect approaches) hold (see Table 5.2).

Knowledge of the potential consumers' needs is a prerequisite for a consumer-oriented product development process. Consumers can have a need without having a specific solution in mind to fulfil this need. *Needs can be investigated without specifying a product*. In other words, need assessment does not necessarily require a (concept of a) product (assumptions 5–8 are no longer required). If consumers are unable to articulate their future needs or rank pre-specified needs (assumption 4), then indirect approaches of need assessment like problem inventories or observation studies can help.

3.2. Combine Consumer Research with Market Structure Analysis or Futures Research

3.2.1. Strategy 2A: Combinations of Need Assessment and Futures Research

When assumptions 2 (usage situations and behaviours do not change significantly) and 3 (no new needs emerge) do not hold, need assessment becomes impossible and trend analysis and scenario analysis can, to some extent, help. Trend analysis can indicate how needs have been experienced in the course of time. Trend analysis can also indicate which aspects in the environment have an effect on the needs. If various aspects will stimulate or block the need in the future then a discontinuous change in the way, this need is felt, can be expected. If a limited number of aspects can be distinguished in the environment that has an important relationship with the need, yet the development of these aspects is uncertain, then scenarios can be built. These scenarios can describe how the needs evolve and in which alternative usage situations they may emerge. If it is possible to present these situations in need assessment tests then the problems with assumptions 2 and 3 are solved.

3.2.2. Strategy 2B: Combinations of Consumer Research and Market Structure Analysis

If the demand side of the market is not leading for developments, then consumer research has to be complemented with market structure analysis. Market structure analysis focuses on the combination of actors both on the supply and demand side of the market rather than on the potential consumers alone. So, market structure analysis takes a much broader perspective. Examples of market structure analysis methods are Porter's five forces (Porter, 1980) and Kotlers marketing environment model (Kotler, 1991). Market structure analysis also delineates the potential market of a major innovation, and thereby may help to focus the consumer research efforts on specific market application areas. The average evaluation of a radically new product by a large group of respondents without distinguishing application areas in the market may discourage its introduction (Tauber, 1974). A lack of focus may conceal the fact that subgroups strongly hold different views. In most cases, during the market adaptation phase, these types of products only attract a very small group of potential consumers that need the innovation in specific application areas.

An illustration of the complementary information from market structure analysis and consumer research is provided by the case of electric vehicles. Three successive consumer research projects investigated the consumers' wants and demands with regard to an electric vehicle for transportation (Armstrong & Overton, 1971; Wilton & Pessemier, 1981; Urban et al., 1996). In all cases considerable percentages of respondents (about 20% of the car owners) showed interest in an electric car. Consumer research indicated a large market potential. However, the actual market results until now disappoint. Apparently, consumer research does not suffice to infer the market potential. A market structure analysis would have investigated when electric cars of good quality (that means with an acceptable driving range and speed and with easy and quick recharge facilities) could be delivered for a reasonable price. A market structure analysis would also investigate whether actors on the supply side of the market are inclined to install infrastructural requirements (like recharge stations).

Table 5.3. Assumptions that Have to be Met for Market Structure Analysis.

Market Structure Analysis	Applicable When
• Describing the most important actors their role and their strategy on the supply and demand side of the market as well as with an indirect effect on the market • Market environment models • Five forces model	9 Market exists already; actors on the supply and demand side are in the market 10 Market constellations evolve gradually (no unexpected events that disturb the constellation)

The combination of consumer and market structure analysis may help when the demand side of the market is not leading for the developments. However, valid results from market structure analysis require that new assumptions have to be met Table 5.3.

This can be considered an adapted approach of market structure analysis only requiring that assumption 9 holds while assumption 10 does not have to hold.

3.2.3. Strategy 2C: Combinations of Market Structure Analysis with Other Methods

Just after a breakthrough technology is introduced in the market, an erratic market situation emerges in which actors enter and leave the market. As a result, alliances become unstable because of the change in actors and because the technology still develops without fixed standards, while products on the basis of the technology are introduced in the market. So, just after the market introduction of a breakthrough technology, it is very likely that the assumptions 10 and 11 will not hold. Different approaches can be adopted to overcome this problem.

Market structure analysis may indicate the actors currently in the market; it may also indicate potential entrants or parts in the market where new companies have room to enter. Christensen, Anthony, and Roth (2004), for example, try to predict discontinuous changes in industries using theories of innovation and market structure models. They describe the possible industry players that may disrupt the industry and thereby advise where business intelligence (of incumbent companies) should look for in their search for potential competitors. They use theories to describe the customer segments, the disruptive innovation may be targeted at and thereby advise what market research carried out by the disruptive company should look for and what type of customer segments should be targeted.

An alternative approach is to combine market structure analysis, trend analysis and scenario analysis. Trend analysis may indicate which aspects in the market environment are likely to evolve gradually and which aspects are uncertain. The uncertain aspects in the market environment that have a direct and strong effect on the market potential of a new technology and may, therefore, be used to form alternative scenario's, each of which is characterized by a market structure. The result of alternative strategies of companies trying to commercialize the breakthrough technology in these scenarios can be used to select a "robust" strategy.

3.3. Circumventing Traditional Market Research and Futures Research Methods

When the validity of the results is monitored and the adaptations and combinations described in the previous sections do still not lead to valid results, then alternative approaches are required. Two strategies will be described: (1) use theoretic approaches so traditional market research is no longer required; (2) deliberately try how the market reacts to specific products and adapt the type of product accordingly.

3.3.1. Strategy 3A: Use a Theoretic Approach to Model the Demand Side of the Market

Potential consumers may be unable to validly indicate their opinions, preferences and requirements for new products which are very different to what they are used to. In some cases even adaptations and combinations of market research methods do not help. The theory of social imitation can be of value in these cases. Social-psychologists place importance on the role that imitation has in our mechanisms of learning (e.g., Bandura, 1977; Hogg & Abrams, 1988; Tomasello & Carpenter, 2005). Imitation is also one of the main principles that drive diffusion (Bass, 1969; Rogers, 2003; van den Bulte & Stremersch, 2004). The likelihood that a new product-related behaviour will be imitated among a population of potential consumers can be assessed without asking the potential consumers to evaluate this product.

Recently, Langley, Pals, and Ortt (2005) describe a new method for carrying out this kind of imitation assessment. The method calculates the likelihood that behaviour related to the innovation will be copied by a certain target group. This likelihood is assessed by looking at the match between specific product characteristics and specific characteristics of the customers belonging to the target group. An example is provided by the combination of product-related behaviour that is highly '*distinct from existing behaviour*', and a target group of customers that is very '*innovative*' (more than average open to new experiences). In this case the likeliness of imitation behaviour is higher than for a target group of customers that is average with respect to new experiences.

To apply this imitation assessment assumption 1 (no unexpected groups of potential consumers emerge) should hold because potential segments of consumers have to be distinguished. Assumption 2 (usage situations and behaviours relating to the new product are not significantly different from existing products) can be released because imitation assessment only requires that these behaviours can be distinguished and not that these behaviours already exist and remain the same. In comparison to need assessment this imitation-based approach requires less strict assumptions and delivers results that are more easily applicable in innovation processes.

3.3.2. Strategy 3B: Probe and Learn or Real-Time Marketing

When none of the previous approaches is applicable, then deliberate processes of market probing can be helpful. Lynn, Morone, and Paulson (1996) describe how various companies involved in the commercialization of breakthrough technologies use a 'probe and learn' approach. "These companies developed their products by probing potential markets with early versions of the products, learning from the probes and probing again." (p. 358) "The first step in the probe and learn process is, in effect, to experiment – to introduce an early version of the product to a plausible initial market."(p. 359). The first product is an initial step in the development process, the learning and the subsequent steps are more important than the commercial results of this first product. Examples of a probe-and-learn strategy are provided by GE when introducing the CT-scan, Motorola when introducing mobile telephony and Searle when introducing NutraSweet. Probe-and-learn strategies require large commitment and investments from the companies involved. The technology and the accompanying products that are introduced in the market should be central to the mission of these companies. In fact, the approach hardly requires any assumptions. In some cases both needs and customer groups are distinguished once the probe-and-learn strategy is well underway. Sometimes lead users can be involved in the probe-and-learn process. Lead users experience specific needs before other users do, and they try to develop their own solutions (von Hippel, 1986).

4. CONCLUSIONS

The CIM describes four inter-related processes of change: scientific exploration, technological research, product creation and market transition. These processes form a kind of innovation system. During the development and diffusion of many breakthrough technologies, all these processes are affected simultaneously. Because these processes are interrelated by various mechanisms of feed forward and feed backward an interesting mechanism of change may emerge within the entire system. We focused on a particular feedback mechanism from the market to product development processes, namely methods of consumer analysis to assess the market potential of product concepts prior to market introduction. We started with standard consumer analysis methods: concept testing and need assessment. We formulated eight assumptions for validly applying concept testing (Fig. 5.1). We conclude that in many cases when breakthrough technologies are first introduced in the market a number of these assumptions are not met. It is not possible to formulate in general which assumptions hold or do not hold when breakthrough technologies enter the market as each situation is different.

When assumptions are not met, we propose four approaches: (1) adapting existing methods; (2) combining consumer research with market structure analysis or futures research; (3) using theoretical models; and (4) actually introducing products into the market, learning from the market reactions and adapting the product accordingly. Subsequent approaches require fewer assumptions. The assumptions for each approach are schematically shown in Fig. 5.1. First of all an important question is whether demand-side factors or supply-side factors in the market are seen as most uncertain for the market potential of a breakthrough technology. If demand-side factors are most uncertain then consumer research is a good starting point to assess market potential.

- When all assumptions are met, concept testing can be applied to find out potential customer groups, potential applications and preferred product forms (that incorporate the technology).
- When only assumptions 1–5 hold, adapted approaches of concept testing can be considered.
- When only assumptions 1–4, direct approaches of need assessment are most appropriate, indirect approaches of need assessment are most appropriate when assumptions 1–3 hold.

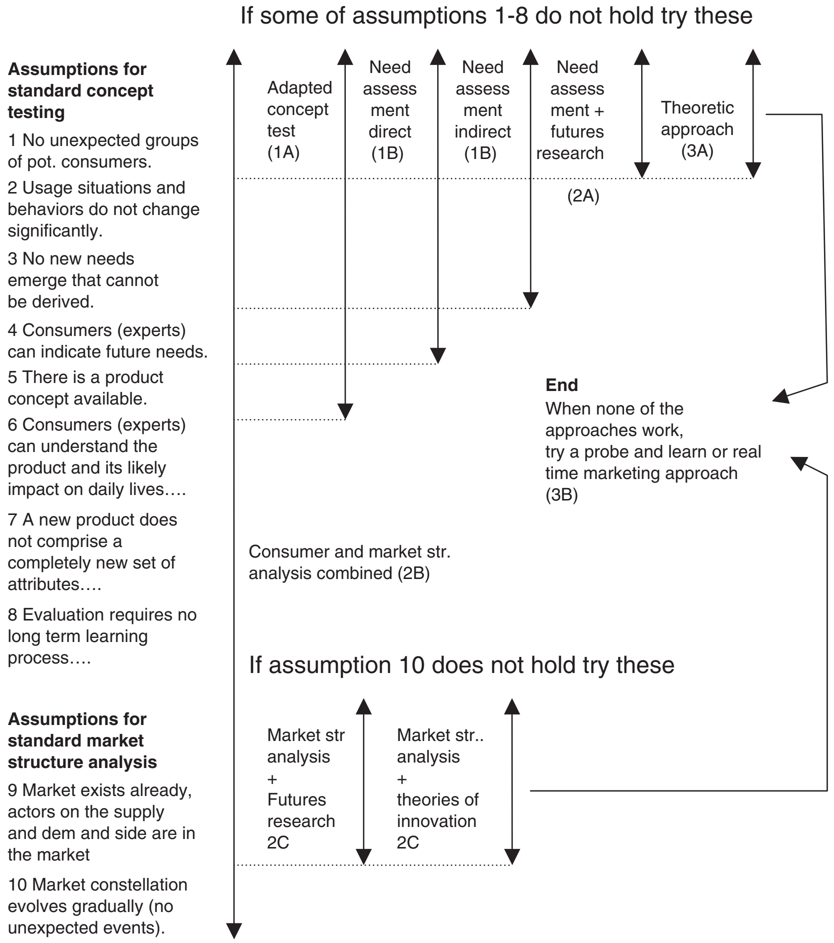

Fig. 5.1. What can be done when one or more of the assumptions for valid concept test results do not hold?

- When only assumption 1 holds, combinations of need assessment and futures research can be applied, or theoretical methods like imitation-based forecasts of consumer adoption can be applied.

When supply-side factors are the most uncertain factor, then market structure analysis is most appropriate. In these cases, new assumptions have to be met (the market and the actors exist already and evolve gradually). If these assumptions do not hold combinations of market structure analysis and futures research are proposed, or theoretic approaches predicting market structure shifts (Christensen et al., 2004) can be applied. In many cases both demand-side and supply-side factors may be uncertain, in which case combinations of both market research and market structure analysis methods will apply.

4.1. Market Analysis and CIM

Fig. 5.1 clearly indicates that when the market developments becomes more uncertain (and consequently less of the assumptions hold that are required for valid consumer research results), the scope of research has to be broadened out to assess the potential of new technologies. The research broadens out in two different directions: more actors have to be monitored and more methodologies have to be applied. First, more actors in the market other than just potential consumers have to be monitored, so consumer research evolves into market research. Market research investigates the behaviour of suppliers, government, distributors, providers of complementary products and services or alternative products and services that might substitute the innovation, and so on. The CIM clearly indicates that to explore the future of breakthrough technologies the focus on these market actors should be broadened out further to include the actors involved in scientific exploration, technological research, product creation and market transition. In Chapter 2, innovations are classified on the basis of the question how many nodes in CIM were involved in the emergence of the innovation. The actors and factors in these nodes should be monitored carefully. Second, Fig. 5.1 shows that when less assumptions hold more methodologies have to be applied. Combinations of consumer research, market structure research and futures research are needed in these cases.

The feed backward and feed forward mechanisms between the processes of change can temporarily allow a kind of steady state in the innovation system. In these cases, extrapolation of past developments can be a good approach to predict the future. However, when these mechanisms disturb the steady state, simple extrapolations no longer hold. In these cases more flexible approaches like 'probe and learn' (Lynn et al., 1996) are most appropriate. The case of the jet-engine illustrated that new approaches to assess this potential are needed. The signal that new approaches are needed is an example of a feed forward mechanism from the market transition to scientific exploration, a mechanism that is located in the lower left part of CIM (see Chapter 2).

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CHAPTER 6

THE ROLE OF INTELLECTUAL PROPERTY IN CIM

ABSTRACT

Intellectual property (IP) and the legal protection thereof are of paramount importance in innovation. IP plays an important role in each of the four fundamental nodes of the Cyclic Innovation Model (CIM). While no one can claim property rights on knowledge in the science node, intellectual property rights (IPR) are essential in the development of new technology-based products (technology node and product node), because it prohibits competitors who did not incur the cost of R&D from unauthorized copying.

1. INTRODUCTION

Intellectual assets (IA) account for more than 20 percent (approximately US$740 billion) of world trade (Harris, 1998). Intellectual property (IP) is a subset of IA that can be legally protected. It is subdivided into five main categories: patents, trademarks, industrial designs, confidential information/ trade secrets, and copyright. Clarkson (2001) offers the following description of these categories: "In general, patents protect inventions such as new medicines or new processes for making something. Trademark law protects words, names, symbols, pictures, logos, designs, or shapes associated with a product (for instance, the name 'Coca-Cola' and the shape of the

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Coca-Cola bottle). Industrial designs protect the aesthetic appearance of a product rather than its functional features. Trade secret law protects concepts, ideas, and factual information kept in confidence, such as customer lists or the idea for a computer program. Copyright law, the last major area of protection, deals with protection of ideas; however, copyright law differs from other forms of intellectual property protection in that it protects the expression of an idea rather than the idea itself.'' Figure 6.1 (from Teece, 2000) lists four of these five main categories of IP and their properties, as applicable in the USA. There are major differences in the duration of protection and the costs involved. For example, the cost of a copyright is very low and the legal protection lasts 50–70 years beyond the death of the creator. A patent is much more expensive and the legal protection lasts only 20 years (Fig. 6.1).

Allison, Lemley, Moore, and Trunkey (2003) estimate that only 5 percent of all patents are ever licensed, while 98.5 percent of all patents are essentially worthless. Bouton (1983) provides the following (frequently quoted) rule of thumb: ''of ten laboratory inventions, only one will receive a patent; only one in ten patents will be licensed by a company, and only one in ten licenses results in more than $25,000 per year in income''. In other words, only one in 1,000 patents yields earnings of more than $25,000 per year.

2. PATENTS

A patent is the exclusive right to use an invention, in exchange for a complete disclosure of that invention. In this way, the patent system stimulates the creation and publication of new knowledge, which would otherwise likely remain a secret for fear of copying of the ideas. This protected openness is an important stimulus for innovation and the basis for the open innovation paradigm (Chesbrough, 2003).

One of the requirements to obtain a patent is that the invention is new, which means that it has never been described in any form anywhere in the public domain. This is referred to as 'prior art', and includes existing patents (which are published after a priority period; esp@cenet (http://ep.espacenet.com), the database of the European Patent Office, contains some 60 million patent documents), scientific journals, conference proceedings, etc. It also includes magazines, newspapers and any other (sometimes unexpected) publication in the public domain. A famous case in this regard is the rejection of a Dutch patent application by the Danish inventor Karl Krøyer. In 1964, Krøyer raised a sunken freight ship in Kuwait by filling it with 27 million polystyrene foam balls (New York Times, March 8,

Characteristics of Legal Forms of Protection in the USA

Considerations	Copyright	Trade secret	Patent	Trademark
National uniformity	Yes	No	Yes	Yes
Protected property	Expression of idea	Secret information	Invention	Goodwill
Scope of protection	Exclusive right to reproduce, prepare derivative works, publicly distribute, display and perform	Right to make, use and sell secret and to protect against improper use or disclosure	Right to exclude others from making, using, selling	Proscribes against misrepresentation of source
Effective date of protection	Creation of work	From date of conception or receipt of secret information	Patent application date	Use and/or filing date of US application issuing as principal registration on or after 11/16/89
Cost of obtaining protection	Low	Low	Moderate	Low
Term of protection	Life of author plus 50 years, or 70 years	Possibility of perpetual protection; or termination at any time by improper disclosure or individual development by others	20 years	Perpetual if used correctly and diligently policed
Cost of maintaining protection	Nil	Moderate	Moderate	Moderate
Cost of enforcing rights against violators	Moderate	High	High	Moderate

Fig. 6.1. Characteristics of legal forms of protection in the USA, for four categories of intellectual property (from Teece, 2000). While the terms of protection for copyrights, trade secrets and trademarks are very long to indefinite, patent protection lasts only 20 years. Furthermore, patents are much more expensive to obtain and to maintain, and the cost of enforcing the legal rights is very high.

1965, p. 58). In 1966, he tried to patent his ‘Method of raising sunken or stranded vessels’ in the Netherlands (patent NL6514306). The Dutch patent examiner found Krøyer’s invention to be prior art, because the same method was used in the 1949 comic book story ‘The Sunken Yacht’, in which Donald Duck raises a ship by filling it with ping pong balls. Even though Krøyer used polystyrene foam balls (not ping pong balls) the method of feeding them through a tube into the sunken ship was considered to be the same technique as used by Donald Duck. The comic book story was therefore considered to be prior art, and Krøyer’s patent application was rejected (Krøyer, 1966).

In lieu of this strict newness requirement, publication is sometimes used as an alternative to patenting, especially when patenting is too expensive. Publication prevents competitors from patenting the (same) technology, and this provides an option for small companies with limited financial resources, who invented a technology which they fear the competition may be close to discovering as well. Mapper Lithography, a Dutch company developing a revolutionary new lithography technology, has used this strategy in the past (Baud, 2003). When financial resources are sufficient, newly developed related or alternative technologies are generally patented as well. This ‘fencing’ strategy (Granstrand, 1999) strengthens the original (core) patent by making it more difficult (expensive) to invent around it. Publication of an alternative puts that method into the public domain, where it becomes part of the state of the art and therefore impossible to patent. Even though the idea is now freely available without infringing any patent, it is not appealing to develop it for the market, because there is no guarantee that the additional R&D costs involved can be earned back. Without a patent protection, competitors are free to copy the final product without the expense of research and development. As Ruud Peters, CEO of Philips Intellectual Property and Standards puts it: “Knowledge without patent protection has no value” (Peters, 2005). Peters obviously refers to value which can be appropriated.

A patent provides the exclusive right to manufacture and market products containing the invention described in the patent. It prohibits others from doing the same thing. This is sometimes referred to as ‘practicing the monopoly’. In certain disciplines, such as pharmaceuticals and biotechnology, this is an absolute necessity, because the high investments (money and time) in research, development, and clinical trials (to establish safety and effectiveness) can only be earned back in the last few remaining years of the patent protection. A patent protection lasts only 20 years. After research, development, clinical trials, and after governmental agencies have finally approved the product for consumer use, only a few years remain to recap the investments (for a new medicine, this generally amounts to \$600–\$800 million). After the patent expires, competitors are free to jump in and manufacture the same product without these costly investments.

Patents are immaterial goods (intangible assets), but they can still be traded. Selling licenses for the use of patented technology can be a lucrative business. For example, IBM has decided that *all* of its patents are available for licensing. In 2005, IBM obtained 2,941 patents. For the past 12 years, IBM has occupied the number one position in the annual top 10 list of companies with the most US patent applications awarded (Table 6.1). Between 1995 and 2005, IBM obtained 29,576 US patents – a impressive 56 percent more than runner-up Canon with 19,014 US patents (USPTO, 2006).

IBM probably owns more patents than any other company in the world. The decision to make all its intellectual property available for licensing caused a lot of initial resistance within the company. It was feared that selling licenses to competitors would undermine the competitive advantage in certain key technologies. However, treating intellectual property as a marketable product also implies that you can patent inventions which are far removed from the company's core business. This insight increased the number of patent applications considerably. Comparing 1995–1996 with 2004–2005, IBM more than doubled the annual number of patents, while Canon's patents increased by only 44 percent over that same period.

Philips has a patent portfolio of more than 100,000 active patents worldwide. In 2004, the company applied for 4,253 European patents (EPO, 2005). Philips is gradually adopting the IBM's strategy of making

Table 6.1. The Top 10 Companies Receiving the Most US Patents in 2005.

Company	No. of US Patents in 2005
IBM	2,941
Canon	1,828
Hewlett-Packard	1,797
Matsushita	1,688
Samsung	1,641
Micron Technology	1,561
Intel Corporation	1,549
Hitachi	1,271
Toshiba	1,258
Fujitsu	1,154

Note: IBM ranks number one for the 12th year in succession.

all its patents available for licensing. These two technology giants have recognized that IP can be a business on its own.

The more common practice is still not to sell licenses for patented technologies which form the basis of the core business, and only sell licenses for non-core-business technologies. While this secures the exclusive right to manufacture and sell certain products, it also invites competitors to 'invent around' the patents. This, in turn, can potentially upset standardization. Depending on the type of product, it could seriously frustrate consumer acceptance of a new product. One may remember the 'battle of the VCRs' in which Sony (Betamax) and Philips (Video 2000) lost their market share to the technologically inferior VHS format. When several different technologies competing to become the new standard in a consumer market application, licensing strategies should aim (on mutually beneficial terms) at motivating competitors to convert to the format most likely to succeed as the new standard.

Motorola practices more than a dozen different IP strategies, such as depreciating IP on non-core-business technology; selling licenses for core-business IP; creating spin-outs on the basis of core-business or near core-business IP; investing in external companies by supplying essential IP.

Over the last 20 years, the number of US patent applications has tripled to the staggering figure of about 350,000 per year (Jaffe & Lerner, 2004, p. 11). Roughly half of all patent applications are awarded, and this number is rising due to the heavy workload of patent examiners. With so many patents to process, the time to assess each patent decreases, which means that there is less time to scrutinize patents for novelty.

3. VALORIZATION AND LICENSING

The Oxford English Dictionary (OED, 1989) defines valorization as "The act or fact of fixing the value or price of some commercial commodity." As discussed above, IBM regards intellectual property (in the form of patents) as a commercial commodity. In this respect, valorization can be defined as turning knowledge into marketable products. Slightly more general, it could also be described as the transfer of knowledge to the market. This knowledge can be in the form of protected intellectual property (patents, copyrights, model rights, etc.), but it can also be unprotected knowledge, such as publications, lectures or even people (with tacit knowledge).

Knowledge created in academic environments is often at best only a semi-finished product. Much work is generally still required to turn it into a marketable product. The main reason is that a university is not a manufacturer of products. Once a newly developed technology is proven to work in a laboratory environment (proof of principle), most researchers move on to new projects. There is no product development department, and therefore no engineering cycle. Following the terminology introduced in Chapter 3, (technical) universities employ Pasteur's Cycle, but they lack Edison's cycle. This means that there is no information feedback to the inventors of a technology, about big and small issues that will inevitably come up during the transition from a laboratory-scale prototype to a marketable product.

Table 6.2 lists the top 10 of patents received in 2005 by universities in the US. The University of California tops the list with 390 patents. In 2004, Delft University of Technology (TUD) applied for 18 Dutch patents. The entire patent portfolio of the TUD contains just a few hundred patents. In 2004, Philips applied for 4,253 European patents. Philips has a patent portfolio of more than 100,000 active patents. Given that a patent protection lasts only 20 years, Philips has acquired at least 5,000 patents per year, or some 14 patents per day – about as much as the TUD acquires in a year.

The difference of scale is obvious. For Philips, the patent portfolio is crucial to the survival of the company. It needs patents to prevent competitors from imitating technologies which Philips invented and developed into products. At the same time, Philips makes a handsome profit selling licenses for the use of its patented technologies. Especially in the fields of optical recording systems (CD, DVD, Blu-ray), television, and other display technologies, Philips owns and co-owns a lot of crucial intellectual property. A special

Table 6.2. The Top 10 of Universities Receiving the Most US Patents in 2005.

University	No. of US Patents in 2005
University of California	390
Massachusetts Institute of Technology	136
California Institute of Technology	101
Stanford University	90
University of Texas	90
University of Wisconsin	77
John Hopkins University	71
University of Michigan	71
University of Florida	64
Columbia University	57

website is devoted to the licensing procedures and pricing details of Philips-owned intellectual property (http://www.licensing.philips.com).

The licensing strategy of the compact disc (CD) technology makes an interesting case, because Philips and Sony (co-owner of the basic patent, and sharing the royalties – 60 percent Philips, 40 percent Sony) had to balance maximizing their revenues from licensing CD technology with the desire to make the compact disc into the new universal market standard. The name of the game was to maximize the product $N \times I$, where N is the number of licenses (expressed in unit volume) and I is the income generated from licensing CD technology (royalties). The main aspects of the CD licensing strategy are: (1) An initial payment of $25,000 for the right to manufacture CDs or CD players. This already generates an income stream, even if licensees never actually produce a single CD or CD player; (2) A royalty fee of $0.03 for every audio CD produced. The fee for Photo CDs, Video CDs, CD-ROMs and other formats is comparable. For CD-R (writable CD) and CD-RW (rewritable CD), the fee is $0.10 per disc; (3) A royalty fee of 2 percent of the net selling price of CD players. That means 2 percent of the retail store price of any type of CD player (home audio, portable, car stereo, etc.), and computer CD-ROM players and burners (see http://www.licensing.philips.com). In 2004, worldwide sales of CDs (audio, data and (re)writable) reached 30 billion units (http://www.answers.com/topic/compact-disc-2). This amounted to an estimated $1.5 billion in license fees, of which Philips got $900 million and Sony $600 million. As a comparison, of all the many universities in the US, Columbia University reaps the biggest benefits from its IP portfolio. In 2006, Columbia University earned more than $206 million from its patent portfolio (Reedy, 2006), despite being ranked only 10th in the top 10 list of the *number* of patent applications by universities in the US (Table 6.2).

4. PATENT QUALITY

What matters more than the number of patents owned, is the value represented by the individual patents. There are several ways to estimate the value of a patent, including development value (how much did it cost to create the technology?), replacement value (what would it cost to develop the technology again?) and liquidation value (the value when forced to sell). The most often used method to estimate the value of a patent is the income approach, which examines the money-generating capability of an intellectual asset. Questions that need to be answered are: what sort of income will the patent generate over time?; how long will that income stream persist?; how likely will this forecasted income materialize? This approach estimates the value of a patent from its market potential – the money that a patent can potentially generate when it is used in new products. Without a detailed study of all possible applications of the technology covered by the patent (including a detailed analysis of competitors, estimated marked share, time to market, etc.) the patent is just another piece of paper occupying shelf space. However, such in-depth studies are time consuming and therefore expensive.

Another approach is to evaluate a patent in much the same way as a scientific paper is evaluated. The importance and impact of a scientific paper can be estimated from the reputation of the journal in which it is published (a paper in *Nature* is more likely to be important than a paper in the *National Inquirer*), and from the number of citations it receives in subsequent years. The status and reputation of the journal is a first filter (quality estimator), which separates the wheat from the chaff. Science citation studies calculate an 'impact score' for individual journals on the basis of the number of citations to papers published in each journal. In simplified form, the impact of a journal is calculated as the total number of citations to all papers published in that journal, divided by the number of papers in the journal. So, a journal with an impact of 1.0 has an average of one citation per article published. The impact of an individual scientific paper is measured by the number of citations it receives in the years following its publication. The more other scientific papers refer to it, the more important it has turned out to be. Even though many objections can be raised against this simplistic quantitative value estimation of a scientific paper, it is one of the few existing objective criteria. The impact of a patent can be measured in a comparable way. Lanjouw and Schankerman (2004) use four different indicators: the numbers of claims, forward citations, backward citations, and the patent family size. Forward citations are citations to the patent in other patents over the five years following the granting of the patent. Backward citations are citations (in the patent) to prior patents, which are believed to be the state of the art closest to the technology described in the patent. According to the Office of Technology Assessment and Forecast, "the number of times a patent document is cited may be a measure of its technological significance." (OoTAaF, 1976, p. 167). The number of claims made in the patent is a measure for the scope of the patent. The family size is the number of parallel patent applications in different countries. Lanjouw and Schankerman (2004) tested their model on 100,000 US patents over the period 1980–1993. According to Trajtenberg (2002), patent counts generally only reflect the effort spent on research and development. Patent counts are not a good measure of innovativeness. However, in specific fields (Trajtenberg mentions computed tomography – CT), patent counts weighted by a citations-based index show a high correlation with the social gains from innovations generated from the patent.

Patents and scientific papers have another thing in common: most will never be referred to again. A conservative estimate is that only one out of every 10 patents is ever used (Basalla, 1998). Yet, it is impossible to determine up front which ones will be important and which ones are destined to remain unused. As it is virtually impossible to patent only 'promising' ideas, companies like IBM and Philips basically patent everything that is patentable. It is reminiscent of a statement by twice Nobel laureate Linus Pauling "The way to get good ideas is to get lots of ideas, and throw the bad ones away."

5. INTELLECTUAL PROPERTY IN CIM

Intellectual Property plays an important role in the four nodes (science, technology, products and markets) and in the four fundamental cycles (Pasteur, Edison, Gates, and Schumpeter) of the Cyclic Innovation Model (CIM; see Chapters 2 and 3).

5.1. The Science Node

In science, knowledge is nobody's exclusive property, and there exist no legal intellectual property rights. Only proper referencing in follow-up research provides an acknowledgment of the original achievement. You cannot patent the laws of nature or the principles of mathematics. Scientists generally publish their findings in scientific books and journals, sharing their knowledge with the rest of the science community. This may be considered as the origin (and the first instance) of open innovation (Chesbrough, 2003). There are some exceptions, however, such as classified scientific research with military applications, and fundamental research in industry. For example, Teflon® (DuPont's brand name for polytetrafluoroethylene, a polymer of fluorinated ethylene) was developed in 1938. Because it was used to coat valves and seals in the first atomic bombs, Teflon® was initially labeled classified. But already in 1946, it was sold commercially and used for civilian applications such as the non-stick frying pan and lubrication products. It is a persistent misunderstanding that Teflon® is a spin-off from aerospace research.

The free (open) sharing of scientific knowledge enabled the gradual building over the centuries of the enormous scientific framework that we possess today. With fundamental contributions from thousands of scientists, and additions and improvements by a great many more, our collective corpus of knowledge laid the foundations for our present day civilization with its highly evolved technology-based lifestyle. This also pertains to the soft sciences, which yield knowledge about human behavior (philosophy, psychology, sociology) and societal structure, patterns and behavior (futures research, economics, management and business sciences). All this knowledge was developed over the centuries, and was openly shared. The combination of openness and the absence of doctrines (dogmas), enabled the sciences to formulate, iterate, and refine its facts, theories, conjectures and hypotheses. To quote Isaac Newton: "If I have seen farther it is by standing on the shoulders of Giants" (letter to Robert Hooke, 1676).

5.2. The Technology Node

Technology can be characterized by completing the sentence 'We know how to …'. Technology can also be the answer to the question 'What is possible?'. Technology is closely linked to the process of inventing, the result of which is commonly called 'an invention'. The European Patent Convention (EPC, 2002) does not explicitly define what constitutes an invention, but rather lists what shall *not* be regarded as inventions: "(a) discoveries, scientific theories and mathematical methods; (b) aesthetic creations; (c) schemes, rules and methods for performing mental acts, playing games or doing business, and programs for computers; (d) presentations of information". Unlike scientific theories (the intellectual assets of the sciences), inventions (the intellectual assets of technology) are acknowledged as the property of the inventor. The patent system was founded to protect inventions from being copied without explicit permission from the inventor. That means that technology is the root of the patent system, which offers legal protection of the intellectual property. One of the requirements to obtain a patent is that the invention must be 'useful' (according to the US patent law). The European patent law elaborates on this further and requires that the invention must be "susceptible of industrial application", which means that "it can be made or used in any kind of industry, including agriculture". That implies that the purpose of the patent protection is to stimulate the manufacturing of products in which the invention is applied.

The patent system is crucial to the concept of open innovation (Chesbrough, 2003), in which the best combinations of various technologies are sought, even if no one company owns all the IP rights involved. It is the logical extension of the insight that some of the best people work for other companies: some of the best technologies were invented elsewhere. Patented technologies are published in the public domain (patent databases), and so anyone can find appropriate solutions to their pending problems. This in itself is not sufficient for open innovation, as the trade-off of protection in return for disclosure has always been the fundamental operating principle of the patent system. True open innovation will only occur when all intellectual property is considered as a tradable commodity. That means that patents should not be exploited to reserve the right to be used by the patent owner only, but to grant licenses to competitors as well. As mentioned in Section 2, IBM is one of the first large companies to consider their entire IP portfolio as a tradable commodity. Other companies (like Philips) are following suit.

5.3. The Product Node

Patents are essential to protect technological products from being copied by competitors. Without patent protection, many products would not be developed because there is no guarantee that the development costs could be earned back. Competition is fierce, and copying is an easy way to steal market share from a company that successfully introduced a new product into the market. One-third of all new products can be imitated in less than six months (Mansfield, 1985), and half of all non-patented new products can be copied by at least half a dozen competitors at less than half the cost of the original development cost (Levin, Klevorick, Nelson, & Winter, 1987).

Increasingly, new products are combinations of several technologies (in many cases patented by several different companies). In CIM, this can be visualized at a lower conceptual level as many-to-one relationships in which different technologies are focused onto a single product (see Chapter 2). In a complex product, such as a mobile phone or a car, the number of patented technologies implemented easily exceeds 100, or even 1,000. These many-to-one relationships can only be realized by combining technologies from different sources: integration. The patent system provides the essential mechanism to facilitate this open sharing whilst protecting against unauthorized use.

Just like many technologies are combined into one product, each technology may find applications in many different products (one-to-many relationship: dissemination). The application of one technology in different products, which may be aimed at different markets, can be regulated in the license agreement. That way, each licensee (the party that obtains a license from the patent-owner, or licensor) can safely occupy its own niche in the market because others are excluded from that particular area of application, despite the fact that they too may have licensed the same technology.

The intellectual property rights of products can also be protected by registering the design of the product (see Section 1). In some cases, the design as laid down in the patent has additional protection through copyright. A famous case in this respect was the infringement of a patent owned by the Norwegian company, Stokke (US patent 4109961) for the Tripp Trapp® children's chair. A cheap imitation of this chair was sold by 13 Dutch companies, including home improvement retailer Gamma. In 2004, a Dutch court ruled that the imitations were an infringement of the copyright, rather than an infringement of the patent.

In another Tripp Trapp®-related lawsuit that same year, Stokke failed to impose its trademark legal right on the Danish company, Trip Trap, because the use of the (very similar) name "had been of a mark which possessed a distinctive character different from that of the mark registered" (Trip Trap, 2006).

Many products are better protected by a trademark than by a patent or a model right. For example, athletics footwear (sneakers) derive most of their value (status) from the manufacturer's logo, rather than from the specific quality of the product. That means that, for imitations to be successful, the imitator must also copy the logo. That is an infringement of the trademark, which is much easier to prosecute than a model or a patent infringement. Another benefit of a trademark is that it lasts indefinitely, as opposed to a patent which expires after 20 years.

Traditionally, computer software relies on secrecy for protection. The (secret) source code is compiled into executable computer code, which is virtually impossible to disassemble and convert back into the original source code. The ongoing debate about the pros and cons of software patents reveals two interesting things. The first is that, in the absence of software patents, protection against the copying of ideas (algorithms; practical implementation) is sought through the mechanism of trade secrets, which hampers progress and innovation. Even though the source code is protected through the copyright law, the underlying ideas are not sufficiently protected from copying. For example, coding the same algorithm in a different programming language might not be an infringement of the copyright law in all cases. The net effect of not having software patents is that an estimated 2–100 billion dollars per year is wasted on recoding software that already exists. This often pertains to basic I/O routines that handle the communication between the processing hardware and the user (interface). For example, code which interprets the pushing of a button on a keypad, or code which makes a symbol appear on a display. This type code is being written over and over again. If software were patented, such I/O routines could simply be acquired through licensing. A patenting system for software would encourage the trading of licenses, which should substantially reduce the development costs by eliminating this senseless repeated coding of the same functionality.

The second point is that the use of trade secrets in the software industry has given rise to the open source community, which operates on the principles of 'take a penny, leave a penny' and 'strength through numbers'. The open source community (most notably GNU and Linux) has demonstrated the enormous resources of the (internet) computer programming community, which dramatically improves both the speed of development and the quality of the source code. And even though the source code of the software is openly shared, it is still protected through copyright. Open sharing is often accompanied by a license agreement wherein it is stated that the use of the software is free, but under certain conditions. Failing to comply with the terms of the license agreement can still lead to prosecution. This collective pool of bright and creative computer programmers has already created serious rivals to some of the world's biggest software products (Linux vs. Microsoft Windows; Firefox vs. Internet Explorer). Because the source code is open and transparent for all to see, errors will be found more easily, and better solutions will emerge than in a closed software development environment. Also, being transparent, open source software hides no secret backdoors, Trojans and other malicious and illegal practices which may be present in closed-source software. (For an unsettling, albeit unlikely example of the opposite, see Thompson, 1984).

While the open source community voluntarily discloses its source code, there is increasing pressure on traditional software developers to open up some of their source code to third parties. The European Communities anti-monopoly act has recently forced Microsoft to share parts of its Windows operating system source code with other software manufacturers, so that they can develop add-on applications for Windows. Despite this involuntary revealing of its source code, Microsoft is still legally protected by the copyright.

5.4. The Market Node

The European patent act specifies that a patent will only be granted to an invention which: (a) is new, (b) is the result of an inventive step, and

(c) has potential industrial application. The United States Patent Office is less rigid, and also issues patents to services, financial constructions and other less tangible inventions. For example, internet retailer Amazon.com has a patent for the one-click ordering service (US patent 5,960,411). Registered customers can order items from Amazon with a single mouse click. Details about the method of payment, the delivery address and the desired shipping method are retrieved from a database. When bookseller Barnes & Noble added a one-click-ordering button (which they called 'Express Lane') to their web store, it violated Amazon's patent (Stanford, 2000). Other examples of non-industrial patents are financial (fiscal) constructions which combine income, mortgage, pension plans and life insurances; ideas for games or TV game shows; a method to experience the love of God (US patent 2,003,152,907).

6. CONCLUSIONS

Innovation is the most important factor for increased wealth and prosperity of a society. In the words of Jaffe and Lerner (2004): "The single biggest factor determining the rate at which a society improved its ability to deliver [human needs and desires] is technological innovation". Technological innovation is expensive. It takes a lot of effort and money to turn an idea into an actual innovation. In the real world, companies are mainly stimulated by the expectation of a financial gain in addition to recouping the money invested in the research and development of the innovation. When the incentive of financial gain is absent, as it is in the development of drugs to cure diseases that primarily afflict people in the third world, new products are not developed despite an adequate patent protection. There is simply no money to be made there.

Not only must an innovation earn back its own research and development costs, it must also make up for all other newly developed products that failed along the way. Only a small fraction of newly developed products turns out to be successful – an innovation. In CIM, an innovation refers to a *successful* new product, process or service. No matter how ingenious, revolutionary, sustainable, etc. a new product, process or service is, it is only considered to be an innovation when it has proven to be successful in the market. To avoid using the description 'new product, process or service' all the time, and to avoid conflicting definitions of the term 'innovation', we suggest the word 'prenovation' for a new product, process or service which has not matured into an innovation yet, and maybe never will. A *successful* prenovation automatically becomes an innovation.

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PART III:
NEW BUSINESS APPLICATIONS

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CHAPTER 7

CIM APPLIED TO THE MOBILE TELECOM INDUSTRY

ABSTRACT

In the telecommunication industry we observe trends such as unbundling, convergence, and new business models. To accelerate innovation, mobile telecommunication companies are more and more working together with companies from other industrial sectors (such as media and IT). The Cyclic Innovation Model helps to understand all those activities in this rather chaotic business environment. This particularly applies to mobile telecommunication companies that are developing mobile data innovations (such as Lucio). All those innovations are steps along a transition path towards a wireless future.

1. INTRODUCTION

New developments in the mobile telecom industry, such as growing transmission bandwidth and sector-crossing business alliances, change the way in which mobile telcos are innovating. Traditional innovation models,

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such as the single-company linear model ('pipeline model'), do no longer explain or describe how innovation occurs today in this industry. In this chapter, we investigate how the Cyclic Innovation Model (CIM) can be applied to this changing mobile telecom industry by specifically looking at Lucio, a mobile data product–service combination introduced into the Dutch market by KPN Mobile. We start with an overview of current developments in the mobile telecom industry (Section 2). In Section 3, a description of Lucio is given, and in Section 4 we will apply CIM to Lucio. We emphasize the new insights the model offers, and we list some lessons learned.

2. DEVELOPMENTS IN THE MOBILE TELECOM INDUSTRY AND THEIR IMPACT ON INNOVATION

Telecommunication has been part of our society for quite a long time, but it currently receives more attention than ever before. Many scientific journals, business magazines, and television programs report on spectacular new technological and market developments in the mobile telecom industry. An interesting example is the uptake of medium broadband GPRS-based services, reaching already a market penetration rate of 70–80% in many European countries (Maitland, Bauer, & Westerveld, 2002). In addition, we see far-reaching changes due to the unbundling of the mobile telecom sector as well as its convergence with other businesses such as IT, television, and other media.

The mobile telecom industry also receives much attention because of negative aspects such as the enormous financial debts (mobile) telecom operators have accumulated due to spending huge amounts of money on UMTS licenses at the end of the nineties to build and exploit mobile broadband networks for mobile data services. The subsequent massive lay-offs of employees from telco-companies (both operators and suppliers), depreciation of UMTS-licenses, and delays of new investments in the mobile telecommunication infrastructure were consequences of their weak financial position.

Nevertheless, there is hope for the future. Drastic cost reductions have worked out and gradually telecom operators obtain the financial space to consider investing again in a more aggressive business strategy. However, merely investing in product development will not suffice. Utilization of the latest insights in innovation processes might be a better strategy. Because underneath the problem of how to improve their financial position, mobile telcos must address the issue of how to innovate successfully. The aforementioned changes within the mobile industry not only impact the structure of this industry, it also affects the way telcos should renew their innovation processes.

The mobile telcos are facing a dilemma: on the one hand they need to develop new business (such as new mobile data applications) while on the other hand they do not (yet) have sufficient resources to invest in these emerging opportunities. This dilemma is exacerbated by the uncertainty on which role to play in a mobile industry that has changed from a simple, linear structure into a complex, non-linear network, often crossing traditional sectoral boundaries. All this affects the environment in which mobile telcos have to work. It forces them to re-think the way they need to innovate.

To characterize the mobile telecom industry, we outline five principal developments. We chose these specific developments because they are, in our view, the most influential to the forthcoming innovations in the telecom sector.

2.1. Increase of Bandwidth

Extending today's bandwidth can be considered as the thread through almost all new developments in the mobile telecom industry. The growing bandwidth largely follows Gilder's law, which states that every 12 months the capacity of bandwidth triples. This trend is illustrated in successive mobile communication standards, starting with 1G for analogue mobile communication (NMT) up to 2G which is the standard for mobile communication today (GSM). We are currently in the 2.5G era, an extension of 2G, which has a bandwidth of approximately 25 kbps. Mobile services in this category are GPRS-type services and 'i-mode'. The forthcoming standard will be Universal Mobile Telecommunications System (UMTS) technology (3G). Initially, it will have a bandwidth of approximately 380 kbps, rising to 2 Mbps. UMTS will enable viewing real-time video via the mobile phone (Lehr & McKnight, 2003). UMTS is an example of technology push. Commercial success will totally depend on new applications and services using this new capability.

The trend of growing bandwidth facilitates new technological capabilities of the communication channel which, in turn, triggers new applications, together defining a range of innovation opportunities.

2.2. Unbundling of the Industry

The telecom industry is being restructured, generally coined by the term ‘unbundling’. This trend refers to the development in which vertically integrated telcos, in many situations the national incumbent operators, are being divided into separate commercial organizations that become independent companies. This important development is initiated by European policy and enforced by national regulators, who liberalize the telecommunication markets. The result is often privatization of the national PTTs (the incumbent telcos), dividing the company into independent organizations. Each can then be offered to the market for mergers or takeovers. An example is the splitting up of the wholesale and retail department, as well as the selling of the network building department of Dutch telco KPN. Unbundling has also a close relationship with the decision of telcos to focus on their core business, and to outsource all activities that are to be considered non-core business.

Telecommunication constitutes a closely integrated system of networks, protocols, hardware, software, peripheral equipment, and so on. Innovation in one part of this system often requires cooperation with other parts of the system. The trend of sectoral unbundling shows that innovation in the (mobile) telecom industry, therefore, increasingly has to occur between different companies that are occupying different positions within the telecom value chain. The combination of different players within the telecom value chain has an important influence on innovation in the sector: innovations are created by partnerships.

2.3. Convergence with Other Businesses

The telecommunication sector in general, and the mobile industry in particular, are no longer an independent business, but have merged in many ways with other businesses. Particularly, they have developed close ties with the information technology business and the media business. This is reflected by the alliances, mergers, and/or takeovers between companies in these different sectors, such as the takeover of Dutch broadcasting company Endemol by Spanish telecom operator Telefonica. Another, more recent example is the decision of Dutch food retailer Albert Heijn, part of global food company Ahold, to sell pre-paid mobile phones in their stores, making them a retailer in the mobile communications industry. Wirtz (2001) mentions three drivers for this convergence-development:

- technological drivers such as digitalization, development of intelligent networks, and the technical convergence of media platforms
- deregulation, that is cross-sector competition spurred by the liberalization of vertical integration and privatization of former state-owned PTTs (see also previous trend)
- demand-related drivers as expressed in changing customer preferences such as individualization of customer relations and systematic solutions

The convergence of mobile communication and Internet also takes place at an individual level, where users consult the Internet via their mobile phone. However, the precise course and consequences of this development with regard to the use of the mobile phone in everyday life are still ambivalent and uncertain (Fortunati & Contarello, 2002; Van de Kar & Van der Duin, 2004).

The trend of cross-sectoral convergence forces mobile telcos to cooperate with companies outside their own industry to ensure cross-sectoral innovation.

2.4. New Business Models

Sectoral unbundling and cross-sectoral convergence have resulted in a rearrangement of the position of telcos in this sector. One consequence is that representation of today's value chain by a linear type of model is no longer valid. Telcos and their partners have different roles and functions. The new product–service combination can no longer be described in terms of a simple pipeline: one company supplying another company higher up in the value chain which supplies the next company, etc. Instead, the structure of this new business model looks more like a network or 'web'. Notions like 'value network', 'value web', or 'business-matrix' are used to describe the complex business interactions of the mobile telecom industry (Ballon, Helmus, Van de Pas, & Van de Meeberg, 2002; Maitland et al., 2002; Sabat, 2002; Li & Whalley, 2002).

This trend of doing business in multi-sectoral networks forces mobile telcos to innovate differently than ever before. Innovation processes are no longer linear and do not have a clear finishing and starting point. Instead, innovation processes can take off almost everywhere in the network, and companies operating inside the network have to adapt continuously to achieve their most optimal position.

2.5. New Services

The effects of new cross-company technology and new multi-sector business models are reflected in the development and introduction of new services in the mobile telecommunications market (both business to business and business to consumer), most of which are not yet very successful. These new services are extending the traditional telecom portfolio far beyond voice-type services. The new mobile services contain an important data element. Table 7.1 summarizes which service categories can be distinguished and which specific services belong to one category for both the consumer and business markets (Preez & Pistorius, 2002). It shows an explosion of new services.

The use of new services again triggers the demand for new services, which again may force companies to reconsider their innovation programs: ‘the circle of change’.

In addition to the trends above, other relevant trends are: growing substitution of fixed telephony by mobile telephony, new entrants obtaining 3G-licenses (besides incumbents), diversifications of 3G-technologies (not only UMTS), telecommunication companies starting to offer ‘triple play’ (bundling of telephony, Internet, and TV services), the rise of seamless connectivity and ambient intelligence, and telecommunication devices providing more personalized content. These trends also have a pervasive impact on how mobile telecommunication companies are innovating since these trends change drastically the ‘rules of the game’, the relationship of the mobile telecommunications industry with other industries such as media and television, and the competitive arrangements between different telecommunications companies.

3. LUCIO

Lucio is a mobile data service that was introduced into the Dutch market at the end of 2002. It enabled employees of companies to access their business information (such as e-mail, agenda, address book, and Internet) while they were mobile. It was offered as a package of different product–service components implemented by a certified system integrator. The mobile device is a Personal Digital Assistant (PDA). Other components that are needed to deliver and to use the service are a mobile infrastructure (e.g., GPRS) and a Virtual Private Network (VPN) – gateway at the premises of the customer. All components are based on a Microsoft Exchange server on a local access

Table 7.1. New Mobile Data Services for Different Consumer and Business Segments (Preez & Pistorius, 2002).

Market Segment	Service Categories	Specified Services
Consumer	Information services	News headlines; market and financial information; new movie releases; "what's on"
	Personal Information Management (PIM)	E-mail; contact lists; shared scheduling; customized alerts for stock market prices or auction bids
	Location-based services	Directions from current positions to a specified location; queries for various facilities (e.g., hospital and restaurant) in the user's vicinity
	Entertainment	Video and audio on demand; mobile betting and gaming
	M-commerce	Mobile banking, shopping, and stock trading; mobile auctions; e-booking and ticketing
	Interactive communications	One-to-one or multiple participant text-based chat; video telephony, and conferencing; interactive games. Remote control of appliances (e.g., alarm/VCR setting)
Business	Remote access to information	Sales force automation through access to stock, product, and customer information; remote access to intranet or other corporate repositories; e-mail; online telephone directories
	Job and information dispatches	Informing field staff of their next assignment (e.g., plumbers, electricians, and technical support staff). Sending of information to multiple recipients (e.g., notifications of meetings). Focused/personalized advertising
	Remote transactions	Remote control of processes and devices; placing and processing customer orders
	Telemetry/device-to-device (*or: machine-to-machine*)	Price changes being sent from a central controller to all vending machines; meter readings; remote vehicle diagnostics

network (LAN) and a firewall. Lucio was developed by KPN Mobile, a Dutch mobile operator and service provider, in cooperation with Hewlett-Packard and Microsoft. Lucio was marketed by KPN Mobile as a service that is a 'guaranteed total solution', a 'reliable service', and 'easy to use'.

It is essential to view Lucio as an innovation by combination (Van den Ende, 2003, p. 1505): innovation is not at a component level but at a systems level. Lucio represents the combination of several components:

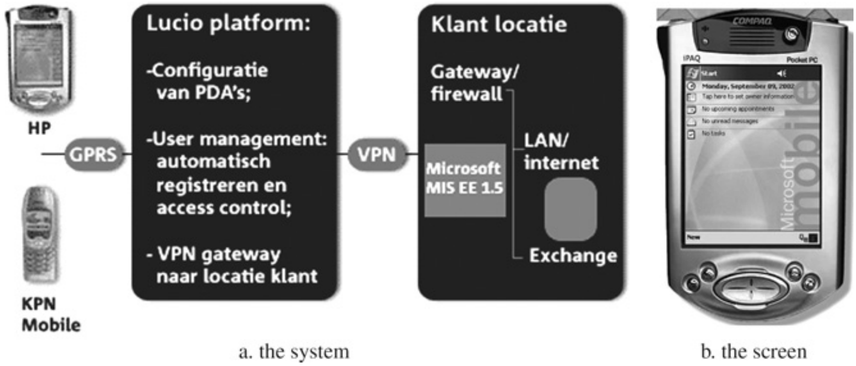

Fig. 7.1. Lucio: a mobile system with a PDA and a mobile phone connected to the company's VPN by using GPRS.

infrastructure (GPRS), device (mobile phone or PDA), software (e.g., information manager), hardware (e.g., intranet, mailservers), and actual services (e.g., e-mail, agenda). The integrated character of Lucio implies that it cannot be developed by a single company. Today, no single company possesses the knowledge and experience to develop such a product–service combination.

Fig. 7.1 shows schematically how Lucio is connected to the company network and how it uses different components such as a PDA, network elements (a VPN gateway, LAN), and software elements (Microsoft Exchange). As stated above, Lucio is a cross-company innovation. Below we show the principal business partners and their role in the development of Lucio:

- KPN Mobile: supplier of GPRS-based services, providing secured connection with the customer's local network.
- HP: provider of mobile devices (i.e., the iPAQ 3870), and the ProLiant server.
- Microsoft: provider of software for PDA-device (Pocket PC operating system), and the Management Information System.
- Certified system integrators (such as The Vision Web, Flex IT, and CSS): providing support to suppliers and customers, and connecting the company network to the mobile network.

Lucio may have a large added value for its users. This is illustrated by two examples:

1. 'MOJO Concerts', the biggest Dutch organizer of pop-concerts and other big events, is an intensive Lucio user. Employees of MOJO use Lucio for

their contacts with the agents of artists and theatres. Employees of MOJO, responsible for operational actvities, use Lucio for fast communication such as changes in drawings of the stage that has to be built, or updating the list of VIPs that attend an event. An important incentive for MOJO to use Lucio is that many of their employees are mobile most of the day. And because Lucio functions independently of local telecom infrastructures, MOJO considers Lucio to be a reliable service.

2. Lucio enables employees of Dutch organization 'Sité Woondiensten' (management of rented houses) to control their appointments, to access the company's information system (e.g., giving the latest information about houses to real estate agents), and to synchronize their mobile devices with the Outlook application at their workplace. Given the large amount of houses and the frequent changes, many employees are involved. It is important for Sité that Lucio prevents their employees the embarrassment of making double appointments. In addition, they have access to real time information about their portfolio.

In conclusion, with respect to the principal developments summarized in Section 2, Lucio represents an early example of a mobile data service that makes use of a transmission technology (GPRS) with a higher bandwidth than the standard technology (i.e., GSM). It is a service that is not developed and operated by one telco (unbundling), but the result of a joint effort of mobile telcos with companies from other sectors (convergence). It has a different business model than 'plain old telephony' (POT), and it is one of the first mobile data services that is distinctly different from the conventional voice-oriented services.

4. ANALYSIS OF LUCIO WITH CIM

In this section we apply the principles of CIM to Lucio. This is an exercise in retrospect, as Lucio was not originally developed on the basis of CIM (contrary to the Thixomolding®-case in Chapter 8). Therefore, our analysis of Lucio in terms of CIM was discussed and refined with the product manager at KPN Mobile being responsible for Lucio.

When we reconstruct the innovation process involved in Lucio in terms of CIM, we notice that neither the scientific exploration node nor the technological research node played any significant role. Apparently, new science and technology components were not required to develop Lucio. However, the market transitions node of CIM played a vital role. Much attention was needed to understand the emerging business requirements for access to in-house applications at any time and any place. Results of this research effort were translated to an estimate of the market potential at a very early stage of the project. This was an important starting point for the development of Lucio. An internal paper at KPN Mobile refers to a particular study carried out by IDC (2001), which concluded that almost 30% of the business customers were interested in using a broadband mobile data service that would give them access to their intranet, as well as to the Internet. And more than 20% was *very* interested in using this new service. Because this study also predicted a significant market growth, a major market transition toward the 'mobile business age' was foreseen by KPN Mobile. To realize the predicted market transition, the added value of Lucio was presented to the business community as a product–service combination that offers 'fast and easy mobile access to in-house business applications'. This yielded the functional specifications for the product development node of CIM: a suitable PDA, interface to the GPRS infrastructure, and connection to the LAN of the client. These hardware and software specifications led to requirements for the technological capabilities of partners needed in the integrated engineering cycle: Microsoft for the software, HP for the PDA, and KPN Mobile for the telecom network. In a next step, the constructed image of the future business in the market transitions node could be *backcasted* via the differentiated valorization cycle (lower right-hand side of CIM) and via the product creation node towards the integrated engineering cycle (upper right-hand side of CIM). In the integrated engineering cycle of CIM, the design of Lucio was a joint venture of KPN, HP, and Microsoft. Minor technical adjustments of existing modules were required. The development of a specific Lucio-gateway was undertaken by KPN Mobile.

In terms of CIM, Lucio is a Class 2 innovation (see Fig. 7.2). This tells us that Lucio had a low technical risk (using existing science and technology), a medium marketing risk (using known market segments), and a high cultural risk (using sector-crossing partners).

The product manager of Lucio at KPN Mobile confirmed that one of the major problems was to cooperate with companies from other sectors with different cultures and strategies. For instance, Microsoft regards market introductions as business experiments. This is in conflict with the demand of full reliability, which is of paramount importance to the telecommunication sector in general, and to KPN Mobile in particular. In retrospect, CIM gave

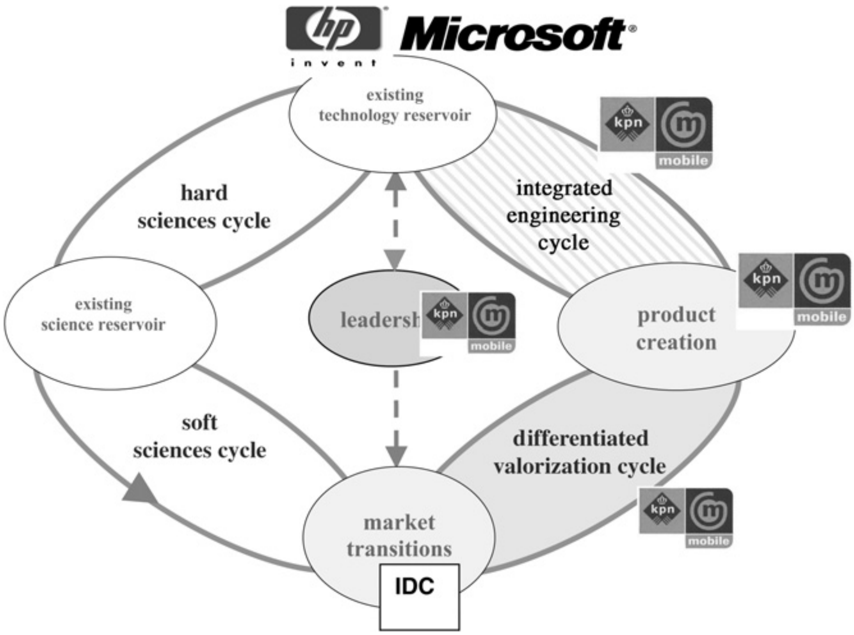

Fig. 7.2. The cyclic innovation model categorizes Lucio as a multi-sector, class 2 innovation, which means that two 'Nodes of Change' were involved.

the product manager better insight into the role of the different companies (see Fig. 7.2). This is important because clarity about the different roles of the different actors turns out to be invaluable in a sector-crossing innovation project such as Lucio. In addition, the use of CIM identifies potential bottlenecks during the development. For instance, managing the engineering partnership was taking place in the upper right-hand cycle, and issues related to the market introduction of Lucio in the lower right-hand cycle. Fig. 7.2 shows that the actors in these cycles needed to bridge these two worlds.

Looking back on the Lucio project, it may be concluded that utilization of CIM at the start would have benefited the project in two ways:

- More explicit description of the innovation process in terms of forecasting the business need at the market transitions node and back casting along the 'circle of change' from the market transitions node to the integrated engineering cycle.

- Better appreciation of the different business partners involved, and their specific role in the innovation process (position in the innovation model). This is invaluable for the new type of entrepreneurship and leadership that sector-crossing innovation processes require today.

We expect that the new generation Lucio will benefit from current technological developments. Some of these developments could become part of the next-generation Lucio innovation process. If such a strategic business decision is taken, the technology node must be included in the innovation process. This could mean the involvement of additional partners. The result is that the entire right-hand side of CIM will be involved, upgrading Lucio to a Class 3 innovation.

'Lucio' is not offered anymore by KPN Mobile. Not because it was not a success but because it has been overtaken by new mobile technologies and, subsequently, new types of mobile data communication (see Fig. 7.3). As such, 'Lucio' was one of the first steps in the ambition of realizing complete mobile communication, having personalized information anywhere and anytime. Compared to modern standards, Lucio is outdated, but nevertheless its introduction can be considered an important marketing step and strategic move by KPN Mobile. For, one of the first time early customers

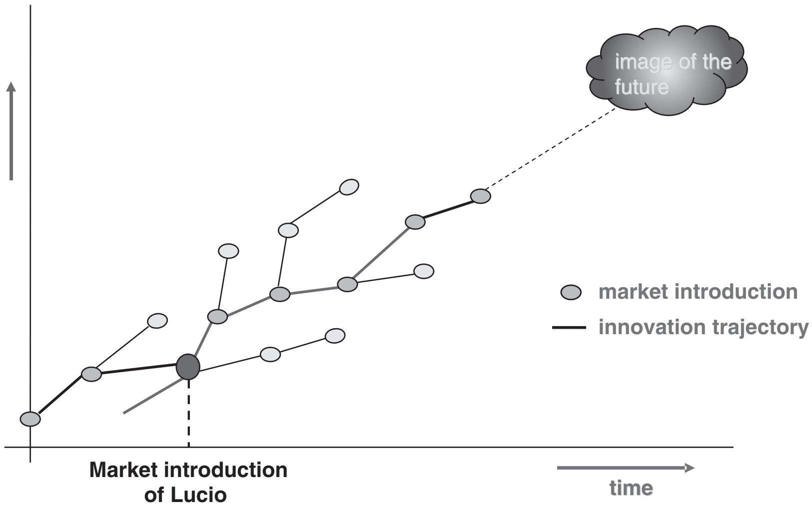

Fig. 7.3. The transition path of mobile communication, showing the market introduction of Lucio.

(i.e., employees) could get acquainted with these type of services. It convinced them of its added value, thereby expressing new demands and wishes to which the telecommunication companies should respond. This is clearly an example of feedback from market transitions to product creation by 'lead users'. In a sense, KPN Mobile with their partners has created their 'own' demand. Today, when we look at all modern mobile data products and services such as 'Blackberry' and, very recently, the Iphone by Apple, Lucio has paved their way.

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CHAPTER 8

CIM AND THIXOMOLDING®: REGIONAL ASPECTS OF AN INNOVATION SYSTEM☆

ABSTRACT

Thixomolding® refers to a new technology to mold a magnesium alloy in elaborate forms. The actors that introduced this technology in the Netherlands first operated on a regional level. With the support of the Cyclic Innovation Model (CIM), the innovation system was able to evolve by developing new innovations, although initially Class 1 and 2 type of innovations. In the future, the Thixomolding® innovation system will compete on a European scale, and it is expected that products will be developed for many different industries.

1. INTRODUCTION

In this chapter, we specifically look at a new technology to mold a magnesium alloy (i.e., Thixomolding®) and describe the regional aspects of its development with the support of CIM.

☆Co-authored by Matthijs Kok

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First, we describe in general how the evolution of innovation processes influenced the regional (and/or spatial) arrangements of innovative activities (Section 2). In short, we describe a historical shift from innovation in singular companies to innovation systems consisting of different companies. In Section 3, we present a specific application of CIM in the Thixomolding®-case. We close this chapter by discussing how CIM can be applied to analyze the regional aspects of innovation systems and argue that regional innovation systems are a specific and temporal version of innovation systems in general (Section 4).

2. CIM AS A REGIONAL INNOVATION SYSTEM

As stated in Chapter 1, the fourth generation of innovation management practices is based on the principle of the *innovation system*. The essence of this generation is that firms no longer innovate on their own, but open up their innovation processes for other organizations (Chesbrough, 2003). This almost automatically means that innovation systems emerge with a regional or spatial character since different organizations are located in different (geographical) places.

According to Carlsson, Jacobsson, Holmén, and Rickne (2002), there are many different types of innovation systems and they can be characterized by dimensions such as a physical or geographical distance, or the amount of dynamics of the innovation system. The traditional input–output systems of innovation processes were static, while the more modern ones contain dynamic (and cyclic) relationships. Every innovation system has the function "to generate, diffuse, and utilize technology" (*ibid.*, p. 235). Regional innovation systems can be considered a subset of innovation systems and have received much academic interest in the 1990s (*ibid.*).[1] Tödtling and Trippl (2005) state that with regard to regional innovation *policy,* no single regional policy approach is optimal. Best practices for regional policies are hard to find which is actually also valid for innovation practices and management in general. So, every region should be approached differently. Also, given the inherent dynamic nature of most innovation systems, these systems are not constant but change over time (Carlsson et al., 2002), which might be the reason why it is so difficult to find best practices that are valid for each type of innovation system (see also Bessant, Lamming, Noke, & Philips, 2005).

In Chapter 1, we described the four generations of innovation management on dimensions such as their main philosophical aspect, R&D management, the starting point of the innovation process (e.g., a new technology), and the degree of openness of the innovation process. In this chapter, we add three dimensions: regional aspects, type of control, and type of knowledge. These three aspects play an important role in (establishing) innovation systems (Table 8.1).

In the first generation, the original R&D institutes were usually built in the proximity of the headquarters and the production facilities of a company and resulted in a kind of central innovation system within a company.

In the second generation, attention was focused on the demand-side of the market because of intensifying competition. Many companies outsourced their basic research activities to universities or specialized research companies in the vicinity of their headquarters.

In the late 1970s until the early 1990s (third generation), companies started to focus on controlling and reducing costs rather than on realizing growth (Rothwell, 1994). Therefore, hierarchically organized companies

Table 8.1. Regional Aspects, the Type of Control, and Knowledge in the Four Generations of Innovation Management.

Generation Dimensions	1	2	3	4
1. Regional aspects	Local R&D and innovation, close to headquarters	More regional innovation, closer to the market (demand)	International innovation processes, technology transfer more international, national markets are opened up	Global innovation, innovation follows international business changes and spatial movements
2. Type of control	Central coordination, hierarchical decision-making	Less central coordination, focus on matching different organizational competences	Control is mainly management of international networks	Control is decentralized within different innovation systems
3. Type of knowledge	Mainly technological, strong emphasis on protecting knowledge	More emphasis on market information market access	More attention to *process management* skills with regard to innovation management	More attention to managing global relationships regarding knowledge production and exploitation

were transformed into more flexible companies. In this context, innovation efforts were closely coordinated in a network of companies. As a result, around the business units of a *company* innovation systems of related organizations emerge.

Between the early 1990s and the early 2000s (fourth generation), technological developments in communication and information technology stimulated globalization of innovation. Globalization forced companies to focus on their core competences (Prahalad & Hamel, 1994). Communication and information technology enabled more dispersed networks of organizations involved in innovation because of the ability to coordinate various activities on a distance. The innovation process has changed from a somewhat closed, singular innovation project to an 'open' innovation system (Chesbrough, 2003). In this system, the supply and demand for innovation subresults, licenses, and so on further disperse the network of companies involved in innovation. Dispersed international innovation systems emerge, in which its specific configuration depends on the type of innovation.

CIM shows that an innovation system is complex: science, business, technology, and markets are (should be) closely related. This means that four different cultural environments need to be interconnected. For regions to be innovative, it is not sufficient that all environments are present and act well, it is essential that they function as an integrated multicultural system in which social capital is built up (Rutten & Boekema, 2007).

However, we often observe two types of system errors. The type one error refers to a region that may be excellent in scientific research, but still underperforms economically because of a valorization barrier between the science and industry community (left- and right-hand sides in Fig. 8.1 make their own choices and plans). The type two error refers to a region that may be excellent in designing and developing technical functions, but still underperforms economically because of a valorization barrier between the technical-oriented and market-oriented communities (upper and lower parts in Fig. 8.1 make their own choices and plans). The failure of the Lisbon strategy of the EU has to be seen above all as a consequence of the existence of these systems errors in the *European* innovation system. The huge emphasis on more research and technology is a far too one sided and simplistic approach.

3. THE THIXOMOLDING®-CASE

In this section, we apply CIM to the development and exploitation of Thixomolding® (see Box 8.1). For a considerate part CIM has been used by

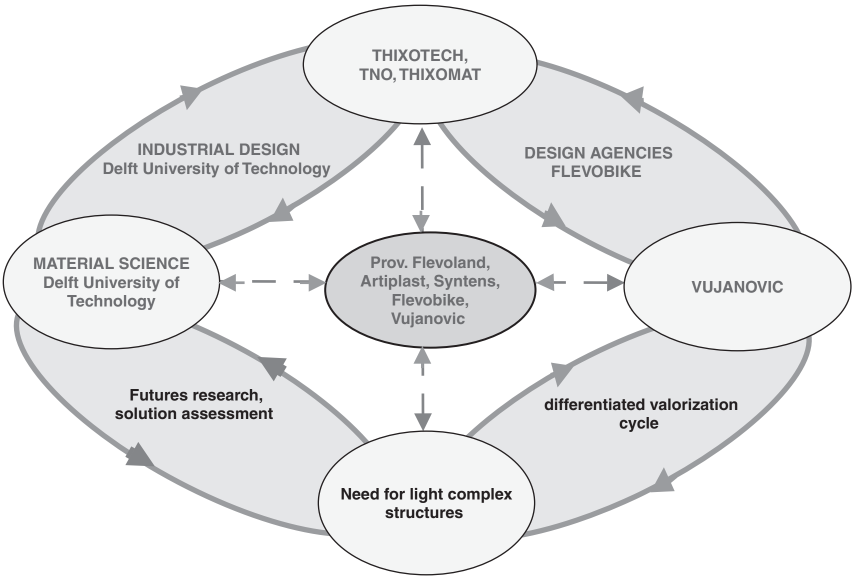

Fig. 8.1. The Thixomolding® innovation system structured according to CIM.

the different actors involved with Thixomolding® as a means to build up and structure the Thixomolding® innovation system. This case study is meant to illustrate the workings and principles of CIM and has been used to prescribe and describe the workings of the Thixomolding® innovation system: the actors, their positions, and the interconnections.

Although worldwide more than 100 Thixomolding® machines are in operation, until 2007 none of them were in the Netherlands. In 2000, a chemical engineer and specialist on injection molding production wrote a business plan for establishing a Thixomolding®− plant in the Netherlands. He contacted an advisor at Syntens[2] in Flevoland (a Dutch province). Because of the complexity and the expected long time horizon of this project, Syntens advised to cooperate with other organizations in developing innovations on the basis of Thixomolding®. As a result, Flevobike Technology and Artiplast (both located in Flevoland) became involved in the project. Flevobike has a great deal of knowledge about bicycle technology and is specialized in developing prototypes in this field. For instance, the company was one of the originators of the recumbent bike. For Flevobike, Thixomolding® means new opportunities for designing and building new bikes and parts of bikes. In light of the company's huge

Box 8.1. The Properties of Thixomolding®

Magnesium is one of the most abundantly available materials on earth. Almost any country in the world and the Netherlands in particular possess enormous stocks of magnesium salts. Magnesium is the lightest construction material that keeps its rigidity characteristics. The specific mass of magnesium is about 30% lower than aluminum. A well-known disadvantage of magnesium is its sensitivity to oxidation. That is why in the Thixomolding® process magnesium is being alloyed with aluminium and zinc. At certain temperatures this alloy becomes doughy, which makes it suitable for injection molding. Thixomolding® is a combination of various existing technologies, among others injection molding, mold production and finishing. The name Thixo is derived from the chemical term thixotrope. Thixotropy involves the behavior of liquids whose viscosity decreases as a result of shift tensions (i.e., it becomes liquid when it is moved). A well-known example is ketchup. With Thixomolding® the result is a unique, tough molecular structure with a high density and without inclosing air. Because there is little shrinkage when it cools off, makes the discharge angles (the angles between the matrix wall and the direction of the discharge of the product) redundant. As a result, less finishing is needed and the product is easier to shape, unlike plastics.

experience with innovation, Flevobike was a logical addition to this project. Artiplast is an injection molding company and produces molds as well. Since at a conceptual level Thixomolding® is not that different from injection molding, Artiplast's knowledge and experience was a welcome contribution to the project.

These three parties formed a strategic alliance called Thixotech Europe. Thixotech Europe was the first holder of a license for Thixomolding® in Europe and its goal is to establish a Thixomolding® plant. They realized that, if they were to reach their goal, they would need to work with other organizations, government institutions, and research organizations. They wanted to form an innovation system (or cluster) with these organizations, and to realize this they founded MagTech Flevoland. Together with Syntens, the Development Organization of Flevoland (*de Ontwikkelings-maatschappij Flevoland* (*OMFL*)), and the Province of Flevoland, MagTech was supposed to have a leading role in developing the Thixomolding® innovation system.

After the initial contacts were established, a kind of structural framework was needed. After attending a presentation about CIM, Flevobike suggested using this model. It was decided to invite scientists of Delft University of Technology to assist in applying this model to their preliminary working relationships and to give advise based on the findings of the application of this model. Consequently, CIM was used both in a descriptive and prescriptive role in the Thixomolding® innovation system. The innovation system was built and analyzed in three phases according to the main principles of CIM.

3.1. Phase 1: CIM as Diagnosis Instrument for the Current Situation

First, in close contact with the original group of organizations, all the actors involved were placed in CIM. In doing so, the following questions were addressed: are one or more cycles underused (or even empty), are one or more cycles over-used, and are the cycles interrelated to each other? This is shown in Fig. 8.1, which indicates that the relationships between most of the actors were not (yet) made explicit and formalized. The transfer of knowledge was difficult as a lack of awareness of their position in the innovation system and their mutual relationships. By establishing these relationships it became clear what their knowledge output is, what knowledge input they need, and which organizations are involved. In this situation, the innovation system was (too) technologically oriented, which was hardly surprising considering the fact that Thixomolding® technology was the starting point for the development of the innovation system.

3.2. Phase 2: Analysis of the Desired Position

What should the Thixomolding® innovation system look like? To answer this question we looked at the dynamics surrounding technology development, which consists of the hard sciences cycle and the integrated engineering cycle (Fig. 8.2). Because it goes too far to show all relationships in this part of CIM, we focus on one of them, namely *prototyping*. In an ideal situation the designers (together with the engineers) combine the design and the technical possibilities. Technical design is then connected to industrial design, after which prototyping becomes highly dependent on matrix construction, with which it is difficult to experiment, due to the high

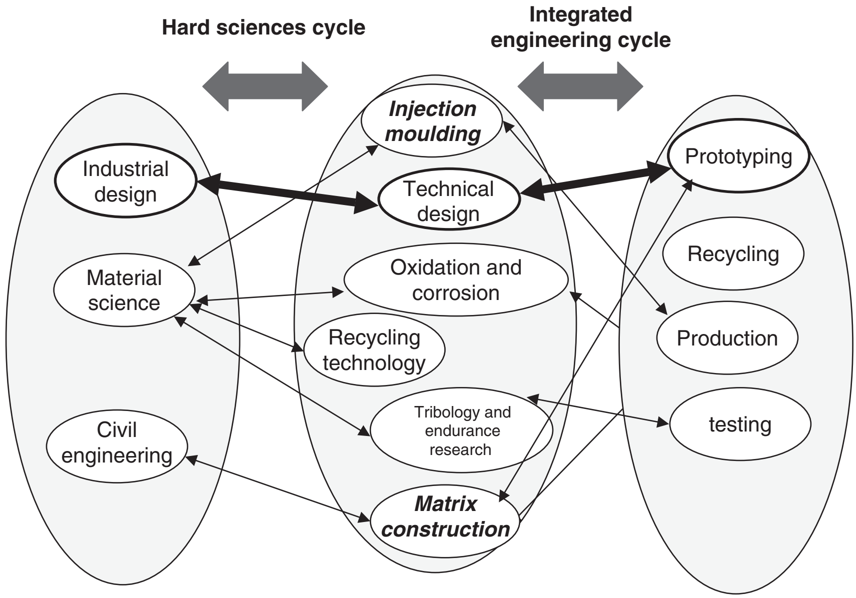

Fig. 8.2. The hard sciences and integrated engineering cycle of Thixomolding® innovation system.

investment costs involved. Building a mold is an integral part of the design, because there is no room to make design mistakes. However, since building molds is not a very innovative industry in the Netherlands, it is necessary to incorporate knowledge about mechanical engineering.

Next, we take a look at the dynamics around market transitions, which consists of the social-oriented sciences cycle and the differentiated service cycle (not included here). The goal is to realize product innovation with a high added value. This goal has become more important since organizations in other European countries already have installed Thixomolding® machines and subsequently can develop a headstart with regard to knowledge about Thixomolding®-based products and experience with exploiting such a machine. So, the actors of the *Dutch* Thixomolding® innovation system should be aware that their 'competitors' are not other Dutch regions but other companies or systems involved with Thixomolding® in other European countries. Possible (international) clients of Thixomolding® products advantage will also be footloose. The Thixomolding® innovation system can apply market research (see Chapter 5) and futures research (see

Chapter 4) to identify potential markets for their products. The increasing European competition has made it necessary to speed up the innovation process and to develop more Class 4 innovations.

An important determinant of the potential success of Thixomolding® is its market image. Image is mainly the territory of public relations and marketing. As far as the Thixomolding® innovation system is concerned, it is important that the first products do not get a bad image as a result of technical failure, which would frighten possible customers. Another aspect is that since Thixomolding® is a type of magnesium certain industries were (and still are) reluctant to buy Thixomolding® products because of it assumed *fear of fire*. For instance, within the aviation industry using magnesium type of materials are forbidden by regulations. Although this is not the case with Thixomolding®, aviation companies stayed reluctant. For the Thixomolding® innovation system, it is important to address this image and legal issue within the soft sciences cycle.

Furthermore, with regard to the soft sciences cycle, a greater emphasis on the development of possible applications of Thixomolding® (e.g., new types of bikes) means that (physical) interaction with customers becomes much more important. If, for instance, Thixomolding®-based bikes will be developed for bike couriers, there will have to be some market research and testing in large cities (e.g., Amsterdam, London, Paris). A consequence of adopting the lead-user concept by Von Hippel (1986) in the development of Thixomolding® in general, is that there will be an emphasis on the market transitions node. Taken to its extreme this would mean that the Thixomolding® *factory* would be merely a production facility producing the main parts and the assembly and incorporation of new parts of the bike would be decentralized, based on the geographical (or spatial) needs and characteristics of users. The Thixomolding® factory may regain some of its position by focusing not only on the mass production of the large parts of the bike (e.g., the frame), but by playing the role of knowledge center as well. As such, the Thixomolding® factory combines an operational and a strategic task in the (national or maybe European) Thixomolding® innovation system. With regard to its regional aspects, the Thixomolding® innovation system will have more spatial levels. There will not only be a regional level (i.e., the Province of Flevoland), but also a local (i.e., local contacts with users to gain information about needs and uses of Thixomolding®-based products) and a national level (i.e., national innovation policies to promote the development and application of Thixomolding®-based products leading even to specific Thixomolding® innovation systems related to existing industries).

So, although the starting point of this innovation system was a technical one, more 'soft' issues (such as market image, regulation, and legal affairs) become more and more important.

3.3. Phase 3: The Transition Path

To get from the current situation to the desired future situation, the Thixomolding® innovation system has to follow a transition path. This transition path has two aspects. First, at the *process side* trust between partners has to be strengthened and network management needs to be established. That is, the long-term relationships must be built up by repeated innovation successes. Network management is needed to make sure that the organization and leadership of the innovation system is professionally and permanently executed. By doing both process activities, a positive feedback can be realized between realizing innovations and gaining access to (new) capital and new knowledge, thereby enabling the development of new Thixomolding®-related products. A successful life cycle will finance the innovation cycle. The innovation system needs to make sure that innovations feed the life cycle quickly enough with new and good products.

Second, most efforts by the actors in the Thixomolding® innovation system is aimed at 'filling' the transition path with innovations. Initially, these innovations are Class 1 innovations whereby the material aspects of current products are substituted by the Thixomolding® material. For instance, tests are being done on making a bicycle frame out of Thixomolding®. So, this transition path is not located in one industry and, therefore, also not in one region, but spreads throughout different industries and regions. It might be difficult for a single innovation system to cope with different transition paths. So, for each transition path a singular innovation system might be established.

3.4. A Regional Perspective on Thixomolding®

The (Dutch) Thixomolding® innovation system comprises a small number of complementary organizations, all of which are regionally based. This arrangement was the result of the simple fact that most of the originators of the Thixomolding® innovation system live in this part of the Netherlands and, therefore, happened to meet. When the province of Flevoland and Syntens became involved, they supported the Thixomolding® innovation system by providing funds and other kinds of support. However, Syntens was suffering from institutional barriers since its advisors were not allowed to spend more than 12 hours on advising this innovation system.

The question remains at what spatial level the Thixomolding® innovation system will operate in the future. Will it stay at a regional level or will it expand? We believe that the current regional scale (i.e., the Province of Flevoland and other regions in Europe) is a temporal one. In searching for new applications, new partners and new expertise, the innovation system will be forced to look outside its immediate geographical proximity. Thixomolding® can be considered a basic technology that is useful to many different industries that may be located elsewhere in the Netherlands or abroad and which will set in motion many different transition paths in other spatial areas.

As far as using CIM as a supporting framework this has the following two consequences:

- The type of leadership will be different. If the Thixomolding® innovation system is reaching a higher conceptual and geographical level, its leadership should move in the same direction, which means that the Flevoland-based leadership will be replaced by a higher (official) authority, or at least one that is capable of operating on a national rather than provincial level.
- Cyclic interactions between various actors become less face-to-face and more (long) distance and anonymous. Although this can be facilitated by modern information and communication technology, it also demands a more formalized approach to knowledge exchange flows, knowledge protection agreements within the system, and arrangements with regard to (possible) revenues, investments, and operational costs.

4. CONCLUSIONS

We will first formulate conclusions with regard to CIM based on the Thixomolding® case. Then, we look at regional or spatial aspects.

CIM turned out to be a useful descriptive instrument for analyzing knowledge relationships within the Thixomolding® innovation system, as expressed in interviews with the actors. It enabled a learning process. A normative application of CIM confirms this: by gathering and mapping all actors and relationships, it becomes visible which actors and what knowledge is missing. The process of filling in all the white spots in CIM is ongoing and is dependent on the chosen strategy (for example, the choice which product–market combinations to develop), which is decisive for the direction of the innovation system.

If CIM is used in a normative way it means that the cluster has to be filled as completely as possible. From a practical viewpoint, however, this does not have to be the best decision. If too fast too many actors get involved then it might endanger the rotation (or circulation) speed, that is, the time to market could be slowed down. Therefore, (new) actors within the Thixomolding® innovation system should not expect immediately a high rotation speed. Indeed, innovation takes time (see Chapter 4). For this a mature and complete organization is necessary as well as experienced managers. These elements are currently not (yet) present in the Thixomolding® innovation system. Therefore, the actors chose to focus on the technology first. Successful cooperation in the engineering cycle might lead to the system becoming broader. Secondly, making the dynamics of the system more manageable is an important reason for having strategic alliances. Changes in the market are in some industries less dynamic than changes in technology. In that case an alliance with market actors is not necessary. An analysis by CIM would mean an emphasis on the engineering cycle. This does not lead to a system failure in our case. Especially the omission of a cycle can make the organization less vulnerable for management failures. However, this does not mean that at the long term this cycle should be excluded.

From a more theoretical view would CIM benefit from linking it with other business theories to make possible that CIM can be used in a more operational way. Now the actors were happy with the structure CIM gave, but for their daily work as innovators CIM was more difficult to apply. So, more practical guidelines to use and implement CIM would be very welcome.

4.1. Discussion of CIM in Relation to Regional Aspects

We close this chapter with three general comments on CIM, innovation systems in general, and their spatial and regional aspects in relationship to CIM, by comparing some of the findings of the Thixomolding® case with literature on (regional) innovation systems:

- Carlsson et al. (2002) discuss the various aspects of innovation systems in terms of their specific structure, level of detail, and the type of internal interaction. For our analysis, it is important to see the physical or geographical dimension as an important dimension of an innovation system. Furthermore, innovation systems are not static entities but evolve over time. The situation we described with regard to the Thixomolding® innovation system reflects an innovation system that, at the moment, is focused on the Flevoland region, but when we take into account the innovation system's ambitions, we expect that in the near future it will start looking beyond its current provincial borders. According to Carlsson et al., this is a natural development because: "the function of an innovation system is to generate, diffuse, and utilize technology" (p. 235) (see also Section 1). In this case, it is especially the diffusing and utilization of the technology that will drive the geographical expansion.

- CIM puts a lot of emphasis on developing the capability to exchange information and knowledge, whereas 'traditional' innovation models pay more attention to how individual organizations can improve their innovativeness. More precisely, CIM claims that the viability of an innovation system is determined by the flexibility and speed by which actors in the four nodes exchange information and knowledge. This is confirmed by an analysis conducted by Ronde and Hussler (2005) into the determinants of regional innovative levels in French manufacturing industries: "... relational competences are an important channel for knowledge spillovers. Without those specific interactions the impact of geographical spillovers is reduced" (p. 1163).
- Fromhold-Eisenbith and Eisebith (2005) distinguish between (innovative) innovation systems that are implemented top-down and bottom-up. They argue that the best way to implement an innovation depends on dimensions such as the geographical scale of an innovation system initiative, regional structural preconditions, life cycle stages, and sector orientation (p. 1265). As stated in Section 3, the Thixomolding® innovation system was initiated bottom-up after which regional governments provided top-down support. As far as the regional dimension is concerned, we feel that the top-down support was motivated mainly by a desire to keep the economic activity around the Thixomolding® technology within Flevoland, a desire that is decidedly less prominent among the originators of the innovation system. Their ambition is to make what they are doing into a success, and if that means having to do business with organizations outside their own region, so be it. Based on this, a top-down approach to supporting innovation systems tends to be more regionally motivated than initiatives that adopt a more bottom-up approach and in which the geographical level is more contingent.

NOTES

1. For an overview of research issues around regional innovation systems, see Doloreux and Parto (2005).
2. Syntens is an independently operating foundation subsidized by the Dutch Ministry of Economic Affairs, whose mission it is to stimulate and promote innovation among Dutch small and medium-sized enterprises (SMEs).

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CHAPTER 9

REVOLUTIONIZING CHEMICAL PRODUCTION PROCESSES USING CIM ☆

ABSTRACT

The Cyclic Innovation Model is applied to a new process for the production of fine chemicals and pharmaceuticals using a combination of ionic liquids and supercritical carbon dioxide. This multi-value innovation combines economic growth with environmental concerns and social value. The most important obstacles in the implementation of this new technology are the successful life cycle management of current production plants, the linearity of current innovation thinking, and a perceived high risk of adoption.

1. INTRODUCTION

In the Western world, the chemical industry has matured and investments have stabilized. One reason is that the lifetime of production plants is much larger than anticipated, due to careful maintenance. Another reason is that smart engineering has increased the capacity of existing plants beyond

☆ Co-authored by Maaike C. Kroon

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expectation. Due to excellent life cycle management, many of today's production processes originated about 20 years ago and are not based on the latest state-of-the-art technology. As a consequence, these processes generate too much waste and are energy-intensive.

Environmental concerns call for new technologies. Recently, new opportunities for radically modified plants have emerged. The production processes involved are more sustainable than the conventional processes due to a more efficient use of resources. Examples are the use of shape-selective catalysts (zeolites) in the butane to isobutene isomerization (Pellet, O'Young, Hazen, Hadowanetz, & Browne, 1996), the use of membrane reactors in the ethylene oxide production (Al-Juaied, Lafarga, & Varma, 2001), and the use of reactive distillation for the methyl acetate production (Huss, Chen, Malone, & Doherty, 2003). These processes combine reactions and separations into one process step, and show a higher selectivity to the main products. The result is less by-product generation (waste) and a lower energy requirement for purification. Despite clear advantages of these new technologies, commercialization is still limited due to the economic success of life cycle management of existing chemical plants.

The most promising technology is the use of ionic liquids as combined reaction and separation media (Earle & Seddon, 2000; Brennecke & Maginn, 2001; Sheldon, Lau, Sorgedrager, Van Rantwijk, & Seddon, 2002; Wasserscheid & Welton, 2003; Welton, 2004). It is possible to carry out highly efficient reactions and separations in ionic liquids, producing no waste and using significantly less energy than conventional alternatives (Kroon et al., 2005a, 2005b). From an environmental point of view, fast implementation of this technological breakthrough is desired. However, with a conventional plan of execution, implementation could take several decades. One important reason for this long implementation trajectory is that innovation processes are traditionally considered as linear chains of causal actions, where each stage requires a considerable amount of time. However, when actions take place simultaneously in all stages of the innovation process, the time between invention and successful implementation can be reduced dramatically. For a fast adoption of innovative technologies, execution should be based on an innovation concept that considers the innovation process as coupled 'cycles of change', where developments take place in all cycles simultaneously (Berkhout, 2000; Berkhout, Hartmann, Duin, & Ortt, 2006). Such an innovation concept is described and subsequently applied to the commercialization of ionic liquid technology.

2. AN INTEGRAL CONCEPT FOR MANAGING MULTI-VALUE INNOVATION

Innovation is generally seen by companies as a necessary investment to stay in business. This is the well-known economic aspect of innovation. However, increasing resource use (e.g., energy consumption) and environmental pollution (e.g., waste generation) give rise to a broader, multi-value role of innovation: how to combine economic growth with a more efficient use of natural resources and a decreasing amount of environmental pollution? This multi-value role is especially important in today's society, where energy consumption and waste generation are strongly increasing due to the growth of the world population and the increase in the standard of living in emerging economies (Fig. 9.1).

According to Von Weizsäcker, Lovins, and Lovins (1997), we could supply the needs of twice as many people using only half the resources, if only we would use better technologies ('Factor 4'). Alternatively, we could increase the quality of life for twice as many people at half the present cost. Therefore, innovation should aim at sustainable business. Multi-value innovation creates economic, ecologic as well as social added-value. It connects three dimensions of societal change (Fig. 9.2).

The multi-value innovation concept is described by the Cyclic Innovation Model (CIM) at three different levels (see Chapter 2). In this chapter, we concentrate on the second level, i.e., the process model, representing the 'circle of change'.

Innovation disrupts the conventional way of doing things. These changes often threaten vested interests, a phenomenon which Schumpeter (1939) called 'creative destruction'. It is therefore not surprising that organizations tend to reinforce a status quo. When a company has successfully invested in an optimized package of technologies for many years to come, it will not easily change this proven way of working. Innovation requires pulling power to overcome this inertia, as well as the determination to change the old processes. Images of an attractive future may generate the required pulling power (Fig. 9.2). Such an image reveals an inspiring new direction and provides a focus on long-term goals. In other words, the image induces the formulation of a promising image of the future (where we want to be) related to the current situation (where we are now) – see also Chapter 4.

Of course, such an image must be shared by all innovation partners involved. When different actors do not share the same vision, their goals will diverge. This is particularly true for long-term projects. Because innovation

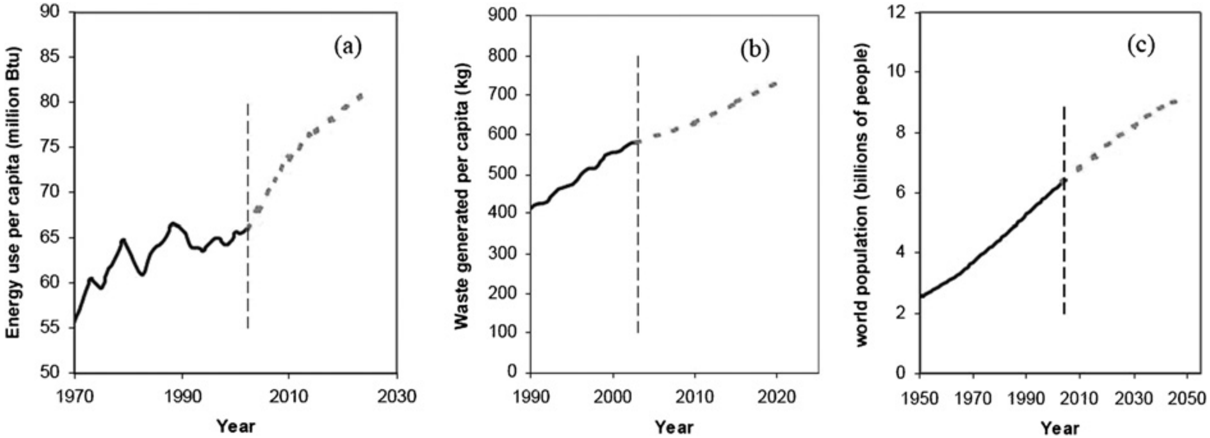

Fig. 9.1. (a) World energy consumption per capita 1970–2025 (*Source*: Energy Information Administration), (b) EU municipal solid waste generation per capita 1990–2015 (*Source*: European Environment Agency); and (c) World population 1950–2050 (*Source*: US Census Bureau Database). Predictions are based on a 'business as usual' scenario for economic growth. The rise in total energy consumption and waste generation is much steeper than panels (a) and (b) depict due to the multiplication by the increase in the world population (c).

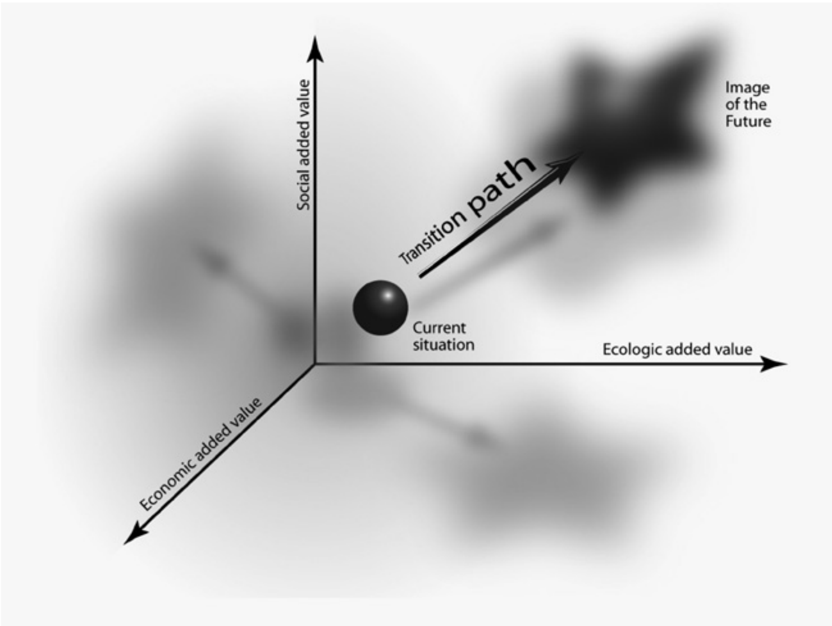

Fig. 9.2. Multi-value innovation aims at the creation of economic, ecologic and social added-value. Multi-value innovation is managed by the formulation of an image for a promising future, the design of a strategy to travel along the transition path from the current situation to the image of the future, and the definition of a plan of execution. In this chapter the image of the future is a low-energy, waste-free production in the fine chemical industry.

is inherently uncertain, returns on investment may not emerge quickly. The risk of decreasing returns in difficult financial periods is large. Only a focus on long-term goals can overcome this problem.

In our innovation project, the image of the future is related to a new paradigm in producing fine chemical and pharmaceutical products. Our target is a quick realization of economic growth with a production process that is low-energy and zero-waste.

The process model to realize the paradigm shift part of CIM, where innovation activities are no longer described by a linear pipeline but by coupled 'cycles of change', connects science with business as well as technology with markets in a cyclic manner. Parallel developments in all cycles accomplish a fast implementation of new technological concepts.

Based on earlier research on ionic liquids (Blanchard, Hancu, Beckman, & Brennecke, 1999; Liu, Abrams, Baker, & Tumas, 2001; Solinas, Pfaltz, Cozzi, & Leitner, 2004), Kroon et al. (2005a, 2005b) discovered a new way of industrial processing in which pure fine chemicals and pharmaceuticals can be produced efficiently without any waste generation, and using only a very low energy input. This innovative way of processing makes use of ionic liquids as solvents. It is both economically and environmentally significantly more attractive than conventional production methods. In addition, the process guarantees safe operations. Section 3 gives an overview of the latest developments in the production of fine chemicals and pharmaceuticals using ionic liquids, formulating an ambitious image of the future. This is a future where more fine chemicals and pharmaceuticals can be safely produced using less raw materials, significantly less energy and zero waste. A strategy is developed to overcome problems along the transition path. The mode of execution is based on CIM. Section 4 contains a short summary of this process model, which is subsequently applied to the use of ionic liquids. Recommendations that will lead to a fast implementation of this new way of processing are formulated in Section 5. It should lead to a step forward in the realization of a more sustainable chemical industry.

3. HOW TO REVOLUTIONIZE THE FINE CHEMICAL AND PHARMACEUTICAL PRODUCTION PROCESS

3.1. Current Situation

The chemical industry is under considerable pressure to replace many existing processes by new technologies aiming at a zero environmental footprint (zero emission, zero waste generation, use of renewable resources, energy-efficient). This is especially true for the fine chemical and pharmaceutical industries, which use a lot of energy (Worrell, Phylipsen, Einstein, & Martin, 2000) and generate a large amount of chemical waste (Sheldon, 1992) per kilogram net product (Table 9.1).

Without change, this energy and waste problem will be even larger in the future, because the production of pharmaceuticals will increase dramatically in our aging society. The world population is increasing; people live longer and will suffer more from infirmities of old age. It is estimated that people over 65 years of age will make up one-third of the total population in

Table 9.1. Production Volume, Energy Consumption (Worrell et al., 2000) and Waste Generation (Sheldon, 1992) for Various Industry Segments.

Industry Segment	Production (tons/annum)	Energy Use (MJ) per kg Product	Waste Produced (kg) per kg Product
Oil refining	10^6–10^8	0.5–10	0.1
Bulk chemicals	10^4–10^6	5–30	1–5
Fine chemical industry	10^2–10^4	20–100	5–50
Pharmaceutical industry	10^1–10^3	50–200	25–100

Western Europe by the year 2020 (*Source*: Eurostat). At the same time, these people can spend more money on medicines that can extend their lives, because their standard of living is increasing (*Source*: Eurostat). Therefore, the costs of healthcare will rise dramatically. These costs would be even higher if the environmental impact of medicine production was realistically accounted for (Box 9.1).

A recent discovery shows that it is possible to produce pharmaceuticals without *any* waste generation and *very low* energy input by using ionic liquids as combined reaction and separation media (Kroon et al., 2005a, 2005b). Ionic liquids are organic salts which are liquid at room temperature and consist solely of ions (Wasserscheid & Welton, 2003). The key property of ionic liquids is that the vapor pressure is negligibly small, so they are non-volatile, non-flammable, and odorless. Therefore, they cannot be inhaled or lead to any emissions into the atmosphere, which makes them very safe to be used in industry. Other characteristics of ionic liquids are a wide liquid temperature range, a high thermal and electrochemical stability, a high ionic conductivity, and good solvency power for organic, inorganic, and polymer materials. The properties of ionic liquids can be adjusted by varying the type of the anions and cations. In this way, ionic liquids can be tailor-made for a specific application. An overview of the properties of ionic liquids is presented in Table 9.2.

When ionic liquids are used in combination with supercritical carbon dioxide (CO_2) as co-solvent, it is possible to carry out reactions and separations simultaneously by using the recently discovered miscibility switch phenomenon (Fig. 9.3): two immiscible phases (liquid phase and vapor phase) can be forced into one homogeneous liquid phase in the presence of compressed carbon dioxide (Gauter, Peters, Scheidgen, & Schneider, 2000).

Box 9.1. The conventional production process of Levodopa, a medicine against Parkinson's disease.

LEVODOPA (1)

One of the most important diseases of the ageing society is Parkinson's disease, which affects men and women equally. Approximately 0.5% of the population in the Western world suffers from Parkinson's disease (Parkinson's Disease Foundation, 2005). Among the 457 million Europeans and 293 million Americans (as of 2005), there are nearly 4 million people with Parkinson's disease (and this number is rising). While the disease usually develops after the age of 65, it is increasingly diagnosed in people under 50 (presently 15% of all cases). The most frequently used medicine for treatment of Parkinson's disease is Levodopa, which relieves the symptoms (tremor, muscle stiffness, slowness of movement, and loss of balance). Treatment requires 0.4 kg Levodopa per person per year (Challener, 2001). Therefore, the potential market for Levodopa is almost 1,600 ton per year. At €2,800 per kg, the annual Levodopa turnover is predicted to be as high as 4.5 billion euros (Parkinson's Disease Foundation). In the conventional Levodopa production process, the waste generation in the asymmetric hydrogenation step alone, is already almost 3 kg per kg product, and the energy requirement in this step is around 17 MJ per kg product (Kroon et al., 2005a, 2005b). The total annual waste generation in all Levodopa processing steps is estimated at 48,000 ton, and the total annual energy consumption at 270,000 GJ (= 8.6 MW).

Using this one-phase/two-phase transformation upon a change in CO_2 pressure, it is possible to carry out reactions in a homogeneous system, resulting in high reaction rates. Moreover, because ionic liquids can dissolve a wide range of catalysts, a reaction can be carried out with very high selectivity and zero waste production. In the biphasic system, the supercritical[1] CO_2 is used to extract the pure product from the ionic liquid phase without any contamination by the ionic liquid, because it has negligible vapor pressure. After extraction with CO_2, the product can be separated from the carbon dioxide by further pressure release. The carbon dioxide and the ionic liquid can both be reused (Kroon et al., 2005a, 2005b, see Fig. 9.4).

This process can produce fine chemicals and pharmaceuticals much more efficiently without any waste generation (no solvent and Catalyst losses).

Table 9.2. Properties and Advantages of Ionic Liquids.

Property	Advantage
Negligible vapor pressure	Non-volatile, non-flammable, odorless
	No emissions possible – safe for environment
	No inhalation possible – safe for health
Wide liquid temperature range	Large operational window
	Total kinetic control
High thermal and electrochemical stability	Large operational window
	No regenerational required
	No formation of toxic decomposition products
High ionic conductivity	Application as low temperature electrolytes
Good solvency power	Application as solvent
	Homogeneous catalysis possible
Tailor-made	Properties adjusted by choice of cation and anion

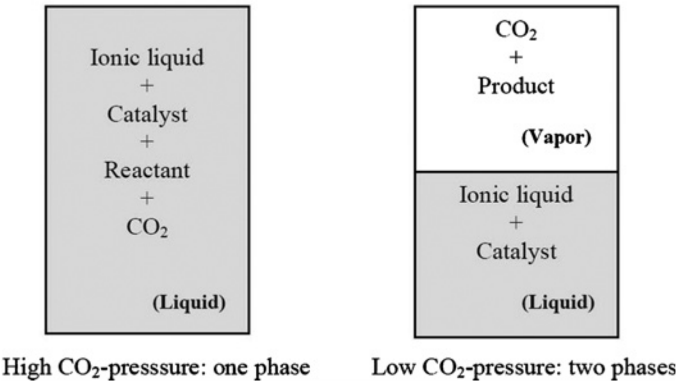

Fig. 9.3. Miscibility switch phenomenon. At high CO_2-pressure a homogeneous liquid phase is formed (in this homogeneous phase the reaction can be carried out at high reaction rate), whereas at low CO_2-pressure two immiscible phases (liquid + vapor) are formed (in this biphasic system the product can be separated from the ionic liquid phase by extraction with CO_2).

The result is a more cost effective use of the raw materials and no disposal costs. The energy consumption is only 25% of that of the conventional production method (energy is necessary only to pressurize the carbon dioxide, not to evaporate a solvent), and operational costs decrease by

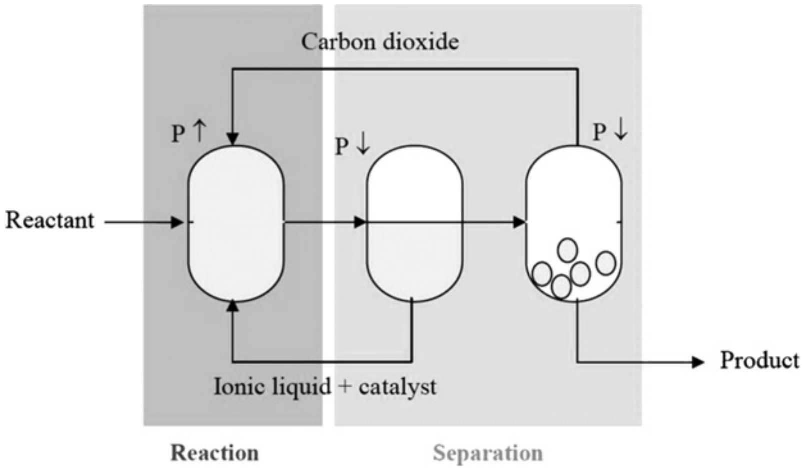

Fig. 9.4. New production process, using ionic liquids and carbon dioxide as combined reaction and separation media (Kroon et al., 2005a, 2005b). At high pressure, the reaction is carried out in a homogeneous phase. The product is separated from the ionic liquid by extraction with CO_2 at lower pressure. The product is separated from the CO_2 by further pressure release. Note the two closed loops for the ionic liquid + catalyst and the Carbon dioxide, respectively.

about 10–20%. All these savings lead to a substantially lower cost price. The new process can be carried out in existing equipment, so no high investments are required. And the production process is very safe, because there are no toxic volatile organic solvents involved (Box 9.2).

3.2. Image of the Future

As mentioned in Section 2, it is most desirable to replace today's chemical processes by sustainable alternatives. Processes using ionic liquids are very energy-efficient, eliminate waste, and avoid the use of toxic and/or hazardous chemicals. Moreover, because ionic liquids are non-volatile (cannot be inhaled) and non-flammable (no risk of burning or explosion), these processes are much safer than processes using conventional volatile organic solvents. In terms of Fig. 9.2, ionic liquids make the business more attractive (economic component), spare the environment (ecological component), and produce medicines safely at lower prices (social component). Lower prices of medicines are most welcome at a time when social security systems are under

Box 9.2. The production process of Levodopa, a medicine against Parkinson's disease, using ionic liquids and supercritical CO_2.

LEVODOPA (2)

It is possible to produce Levodopa using ionic liquids (Kroon et al., 2005a, 2005b). In the new process, there are no solvent (ionic liquid) losses and catalyst losses in the asymmetric hydrogenation step (compared to a loss of 3 kg methanol and 0.3 g catalyst per kg Levodopa in the asymmetric hydrogenation step of the conventional production process). The energy requirement in this step is only 4.8 MJ per kg product (compared to 17.2 MJ per kg product in the conventional process). Based on the potential market of 1,600 ton Levodopa per year, using ionic liquids in the asymmetric hydrogen step 20,000 GJ of energy, and prevents a waste stream of 4,800 ton methanol and 480 kg catalyst.

pressure and the cost of healthcare is increasing due to the ageing society. The higher affordability of these medicines will improve the quality of life for many people worldwide (Fig. 9.5).

3.3. Transition Path

A strategy has to be designed to travel along the transition path from the current situation (energy-intensive, waste-generating industrial processes) to the image of the future (low energy, zero-waste industrial processes) with minimum delay. There are a number of obstacles along this transition path that must be overcome to realize a fast implementation. These obstacles are:

– successful life cycle management of current production plants
– a risk averse chemical industry
– linear innovation paths causing long times to market

Investment requirements are an important obstacle in the adoption of the new production process. In the current economic structure of the chemical industry, the lifetime of production plants is long and returns on investment are low. Therefore, new technologies requiring large capital expenditure are unlikely to be adopted from an economic point of view. This hurdle has seriously limited a more widespread use of promising technologies in the

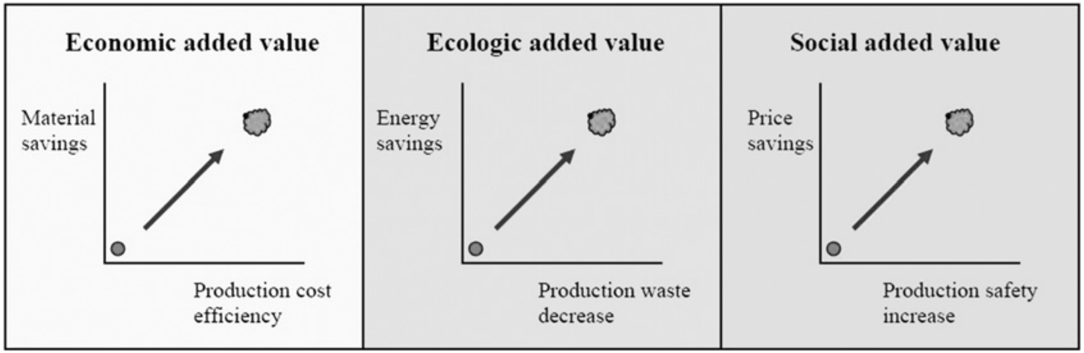

Fig. 9.5. Image of the future. The new production paradigm leads to a future with savings on raw materials, energy and prices. It also leads to a production process with less cost, zero waste and improved safety. Note that this figure shows that each of the three added-value dimensions in Fig. 9.2 represents itself a two-dimensional parameter space.

past. A second obstacle on the transition path is uncertainty. A new way of processing always involves risks, because the concept has not yet been proven on a large scale and on the long term. Therefore, as long as the current production method is making an acceptable profit, industry will be risk averse and stick with optimizing current production concepts. Radical change must primarily come from environmental and social forces, rather than from economical incentives.

Fortunately, the situation for the proposed new production process is more positive. No large investments are required, because the new production process can use existing equipment. In the fine chemical industry, supercritical extraction is already applied (King & Bott, 1993), and this equipment can also be used to carry out the new process. Moreover, when industry not only takes economic considerations into account but also the environmental impact of their activities, the overall advantage of the new investment is even greater.

The obstacle of uncertainty can be overcome by demonstrating the use of ionic liquids under practical conditions for prolonged periods of time. Until recently, the long-term process aspects of ionic liquids (such as the long-term stability, availability, costs, and impact on the environment) were unknown (Chemical Industry Vision, 2003). However, cooperation between companies (Merck, BASF) and universities (Delft University of Technology, Queen's University of Belfast, University of Erlangen-Nürnberg, University of Notre Dame, University of Alabama) has resulted in a 'proof of concept' for a number of ionic liquid processes. In collaboration projects, properties of ionic liquids that are needed for their implementation in industry have been evaluated. These projects show that most ionic liquids are stable under both oxidative and reductive environments, low toxic (comparable to the lower alcohols), and biodegradable (Kumar, Ruth, & Kragl, 2003).

Considerable progress toward commercialization of ionic liquids has recently been made. Since the supply of ionic liquids is expanding (more types of ionic liquids with increasing availability from multiple vendors), prices are decreasing fast due to economics of scale (Merck). At the same time, more ionic liquids are demanded because new industrial applications are found. This higher demand does not seem to raise the price, because the supply increases even faster. Ionic liquids are currently used in three commercial applications, and their application is expanding. These commercial applications are BASF's BASIL (Biphasic Acid Scavenging using Ionic Liquids) technology for esterifications (BASF), IFP's Difasol process for the dimerization of small olefins (De Souza et al., 1997), and the safe storage of toxic gases such as BF_3 and PH_3 in ionic liquids (Tempel, 2005). Because of these commercial applications, ionic liquids are no longer regarded as risky, but more as 'proven' technology.

Because the considered obstacles of investment requirements and uncertainty in the adoption of the proposed production process are smaller than perceived, we can accelerate the implementation of the proposed process. Instead of using time-consuming linear innovation paths, we employ an innovation model that considers the innovation process as coupled 'cycles of change'. This will be discussed in the next section.

4. MANAGING THE INNOVATION PROCESS

4.1. Innovating Chemical Production Processes with Ionic Liquids

Fig. 9.6 shows the Cyclic Innovation Model (CIM) for the implementation of the proposed process combining CO_2 with ionic liquids. It is indicated which

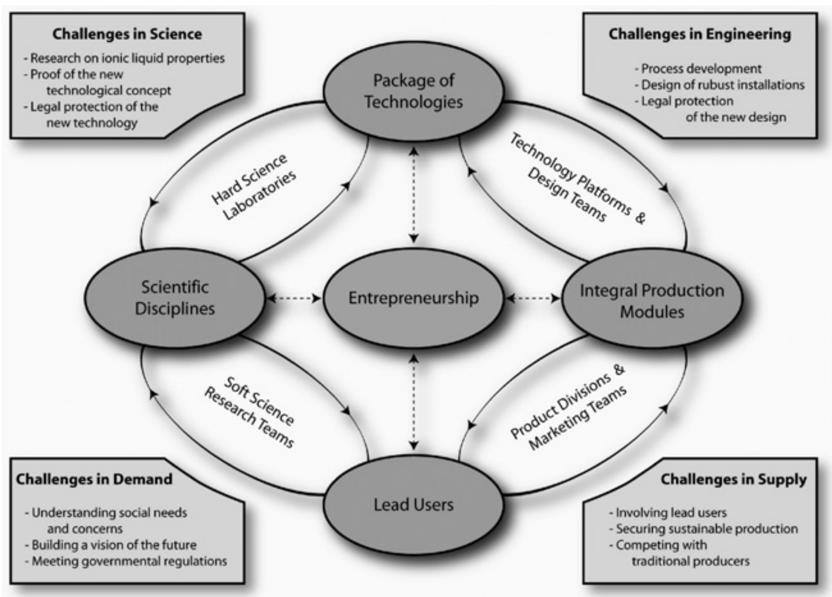

Fig. 9.6. The Cyclic Innovation Model (CIM) for the sustainable production of fine chemicals and pharmaceuticals. Challenges and responsible actors are indicated.

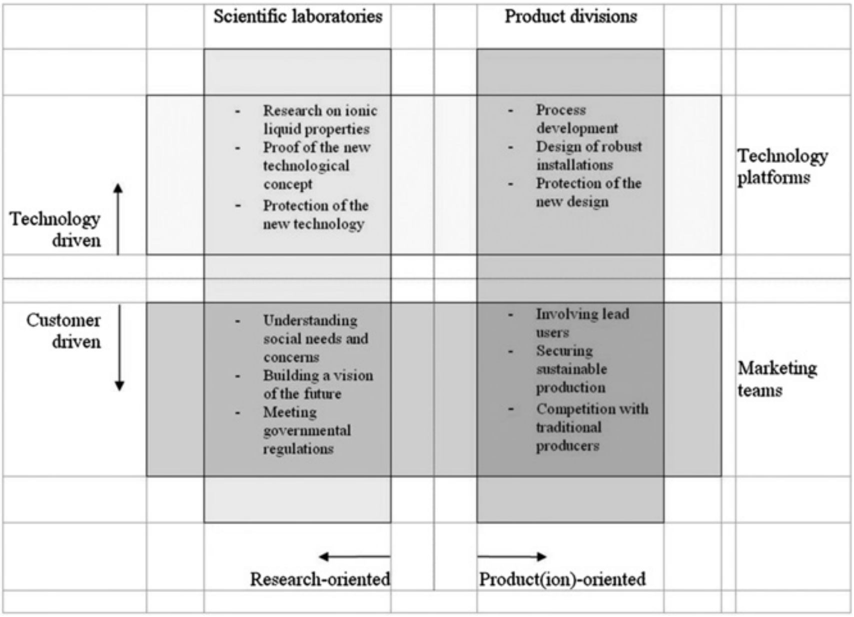

Fig. 9.7. CIM networks representation of the innovation cycles for the sustainable production of fine chemicals and pharmaceuticals. There are four interconnected networks, each network having a matrix topology (Berkhout, 2000).

actors are responsible for which challenges. Fig. 9.7 shows a network representation of the innovation cycles (Berkhout, 2000).

4.2. Challenges in the Market

The market of fine chemicals and pharmaceuticals is growing fast, due to the population growth, the trend of aging and the higher standard of living. The latter makes medicines affordable to more people. Conventional production processes in the chemical industry generate too much chemical waste and use too much energy (see Table 9.1). Since environmental awareness is increasing, the fine chemical industry is under pressure to reduce its waste production and energy consumption. Furthermore, lower prices for medicines are demanded to reduce the increasing cost of healthcare. These forces will drive the forthcoming changes.

Looking at the soft sciences cycle (Schumpeter's Cycle), market-oriented research organizations aim in their studies to better understand and predict the continuously changing needs and concerns in society. Companies use this knowledge to build a corporate vision of the future. Governments should base their legislation on this understanding, whereas in turn the legislation will again initiate new changes.

For example, governmental legislation can force companies to innovate by setting stricter regulations with regard to safety, health, and environment. These regulations should be based on the latest state-of-the-art technology, or, even better, should encourage the development of better technology. Intelligent governmental legislation leads to a faster implementation of multi-value innovation. However, governments should design their policies in close collaboration with universities and companies. This is the essence of the triple helix principle (Etzkowitz & Leydesdorff, 1998).

4.3. Challenges in Production

In the valorization cycle (Gates' Cycle), companies aim to distinguish themselves with the new production process to obtain competitive advantage. Product quality and specifications are set by product divisions in cooperation with lead users. Profitability is a first requirement for securing the sustainable production of fine chemicals and pharmaceuticals. Moreover, marketing groups can use the sustainable image of the company to attract new customers and to confront conventional producers.

The new production process is an example of a process innovation. Industry is not asked to make a new product (it takes at least 10 years of clinical testing before a new medicine is allowed for public use), but to change the way of production. A significant advantage is that the new production method can be carried out by making ample use of existing equipment.

4.4. Challenges in Engineering

The product divisions (engineers from industry) and technology platforms (applied researchers from the hard sciences) must cooperate in the engineering cycle (Edison's Cycle) to develop the ionic liquid technology to maturity. They should test the new production process on a pilot scale and then design robust commercial installations. They must learn all (long-term) process aspects, and know how to optimize the process by smart control. The pharmaceutical industry should share their experiences with the scientific community and stimulate universities to develop solutions to overcome any of the problems that may occur. Also, patent protection of the robust installation design is an important issue.

4.5. Challenges in Science

Scientific laboratories in cooperation with technology platforms must determine the physical and chemical properties of ionic liquids to select a suitable one for a specific application (technical-oriented sciences cycle (Pasteur's Cycle)). Measuring these properties is time-consuming and expensive. It is better to develop scientific models for predicting the properties of ionic liquids. Also, the long-term stability of ionic liquids has to be investigated. Furthermore, ionic liquids should be tried as solvents for various reactions and separations, and kinetics and selectivities should be measured. Multi-disciplinary scientific groups (catalysis, thermodynamics, separation technology) should work together to obtain all this information. Based on these data, a proof of concept for the new technology can be reached and applications for the new technology can be found in cooperation with companies. Furthermore, intellectual property protection for the new technology should be arranged.

4.6. Class 4 Innovation

The new production process is an example of a Class 4 innovation. It is based on innovative contributions in all four CIM nodes. Science provides the foundation for the new production process. Basic research on the properties of ionic liquids has generated new insight for the use of these liquids as novel reaction and separation media. Further technological development has resulted in the discovery of a new safe production method without any waste generation and with low energy input. Sustainable industrial production can be secured by the profitability and the 'green' image of the innovation. It is recommended to introduce a certificate that states that the chemical product is produced in an environmentally and socially responsible manner. In this way, customers can recognize that the new production method meets the needs and concerns of society, now and in the future.

5. CONCLUSIONS

A new production process is described that leads to a future where more fine chemicals and pharmaceuticals can be safely produced using less raw materials and significantly less energy and yielding zero waste.

Fast implementation of this sustainable way of production requires the use of a new innovation concept. The process model of this concept does not represent innovation by a sequential process, but by coupled networks that, in a parallel fashion, connect soft sciences with engineering issues and hard sciences with valorization issues.

NOTE

1. Supercritical refers to a state of a substance at a temperature and pressure above its thermodynamic critical point. In that state, it behaves both like a gas and a fluid: it diffuses through a solid (like a gas), and it dissolves solids (like a liquid). CO_2 above its critical temperature of 31°C and above its critical pressure of 7.38 MPa, is one of the most common supercritical fluids.

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EPILOGUE

The purpose of innovation is to create new business. And an important enabler of innovation is new technology. This means that innovation connects the development of new technology with the development of new business. Together they form a complex environment with a wide variety of activities. We have described this environment by three interconnected layers: *framework for new business*, *cyclic innovation model* and *open technological infrastructure*. An important advantage of this three-layer presentation is that it introduces the context of innovation: innovation is more than technology but it is less than business development. This means that innovation models should refer to this context. We consider the Cyclic Innovation Model (CIM) a good example of such a model.

A fundamental characteristic of the CIM is that it describes a circle and not a chain. Science is not at the beginning of a chain and the market is not at the end. Both are part of a perpetual creative process along a dynamic path that has no fixed starting or ending point: innovations build on innovations. Innovation may start anywhere and anytime. The result is an endless build-up of economic and social value that is realized by the reinforcing cycles along the entire circle. In CIM, new technologies (for example, originating from recent scientific discoveries) and changes in the market (for example, originating from emerging human needs) continually influence each other in a cyclic manner. This dual nature of innovation – technical capabilities and societal needs – will shape the future of socio-technical, socio-economic and socio-cultural regimes. Together with the central role of entrepreneurship, it is considered to be the key characteristic of process models for open innovation.

An important consequence of the cyclic process is that innovation requires early interaction between scientific discoveries and new business ideas, as well as early interaction between technological inventions and new market opportunities: turning scientific knowledge into economic value. These cyclic interactions will not only cross the boundaries of traditional sectors, they will also cross the boundaries of the different stages of innovation. This means that all nodes of the cyclic process model are active in all phases of the transition path: away with the closed pipeline concept in innovation models. An interesting example is the pharmaceutical industry, where the slow and costly in-house pipeline model is gradually replaced by a much more open concept with continuous interactions between actors along the entire circle at all stages of innovation: ‘playing chess at four levels at the same time’. In this way, knowledge from other industrial sectors can be utilized, the long distance between science and markets is significantly decreased – short connections between new discoveries and early users – and new innovations build on existing ones.

An important consequence of the cyclic process model is also that the cyclic networks between the ‘nodes of change’ require multi-partnerships that can start fast, adapt fast and learn fast. This means that in today’s innovation arena the question should not be ‘who is available’ but ‘who is needed’, meaning amongst others that the organization of labour should be revisited: the social aspect of innovation. Today, many organizations are still based on the principles of ‘command and control’. Kanter (2006) concludes that companies should loosen top-down control and tighten bottom-up collaboration.

If we look at national policies, the cyclic process model makes policy makers aware that institutional factors such as governmental rules about the flow of capital, the flow of labour, the flow of information and the flow of knowledge along the circle should be redesigned to facilitate the innovation processes in a much better way. This requires a rethinking of how current governmental organizations think and work.

A STEP FORWARD?

In the beginning of this book (Section 3 of Chapter 1), we discussed the problems of the recent models of innovation management:

1. an integrated model is lacking
2. current models diverge considerably from the actual practice of successful firms
3. current models lack the flexibility to adapt to the context
4. current models focus on technology-product combinations
5. current models focus on creating innovations rather than exploiting them
6. current models are essentially linear
7. current models focus on the level of the innovation project and the R&D organization

At the end of this book we want to give our opinion on the contribution of our concept in solving these problems.

We think that problems 2 – 5 can be explained by realizing that current innovation models fail to bring in the business context of innovation in an explicit manner (see Figs. 2.11 and 2.2). Innovation should lead to new business and, therefore, innovation models should be an integral part of some business development framework. Stand-alone innovation models are not very useful in the practice of business.

We also think that problems 1, 5 and 7 can be explained by realizing that current innovation models fail to give a realistic description how hard and soft sciences contribute to the innovation process and how that contribution relates to the engineering and valorization activities (see Figs. 2.7 and 2.8). The consequences are that the fundamental barriers between the different parts of the innovation system cannot be addressed properly.

And we also think that problems 2 and 6 can be explained by realizing that current innovation models fail to reveal the open networks behind the complex processes of change (Fig. 4.9). This means that in practical situations no useful insight can be given on how these networks need to be managed.

In conclusion, we hope that with our new way of looking at innovation – circular and multilevel – we have given a valuable contribution to all of those who seek new solutions that result in successful market introductions.