VTT Technical Research Centre of Finland

Inducement and blocking mechanisms in the Finnish life sciences innovation system

Patana, Anne-Sisko; Pihlajamaa, Matti; Polvinen, Kirsi; Carleton, Tamara; Kanto, Laura

Published in:
Foresight

DOI:
10.1108/FS-10-2012-0081

Published: 01/01/2013

Document Version
Peer reviewed version

Inducement and blocking mechanisms in the Finnish life sciences innovation system

Anne Sisko Patana, Matti Pihlajamaa, Kirsi Polvinen, Tamara Carleton and Laura Kanto

Abstract

Purpose – This paper aims to identify inducement and blocking mechanisms which impact the development of the life sciences innovation system in Finland. Innovation system analysis of emerging technologies is important for the design of technology-specific innovation policy measures to promote desirable futures

Design/methodology/approach – This exploratory study uses a functional technological innovation system analysis framework designed to identify policy goals for emerging technological fields. The data consist of 33 qualitative face-to-face interviews with senior managers and decision-makers. Best practices are identified from the San Francisco Bay Area and the Finnish life sciences innovation system is analyzed in detail.

Findings – The Finnish system has a good capability to perform top-level basic research, but the commercial aspect is largely missing because of the lack of business know-how, small size of the domestic market, networking failures, scarcity of funding and poor public image.

Research limitations/implications – The two regions have different scopes which prevents direct comparisons between them.

Originality/value – This study applies the technological innovation system model to the life sciences industry. It provides new information on the characteristics of the industry and factors affecting its dynamics. The results can be applied for policy design by policy makers.

Keywords Biotechnology, Innovation policy, Life sciences, Technological foresight, Technological innovation system

Paper type Research paper

1 Introduction

The biotechnology industry [1] traces back to the 1970s when DNA techniques were developed. Today the biotech industry is among the fastest growing fields, characterized by a high rate of radical innovations. In this study, we concentrate on the life sciences industry, which overlaps the biotech field. Life sciences has no universally accepted definition, and the term is often used together with biotechnology or even interchangeably. We define life sciences as functional foods, drug development, diagnostics, biomaterials, bioinformatics and medical design and technology.

The life sciences industry is distinguished by long research and development times, strong regulation, and high risks due to the inherent uncertainty linked to biological processes. The industry also faces challenges related to the complexity and heterogeneity of information and knowledge since it combines many sectors (*e.g*. biology, medicine, biochemistry, chemistry, physics, and information technology), each of which is complex by itself. The ever-increasing stock of information and knowledge gained through basic research makes the life sciences industry highly dependent on academia at all stages of the innovation process (Powell *et al.*, 2007). As a whole, the emergence of the field has its roots in university research (Dalpé, 2003).

The United States is regarded as a forerunner in life sciences research and business. Even though biotech research is considered quite strong in Europe, it clearly lags behind the United States in commercialization (Haeussler, 2011). Still, it was not until 2008 that the biotech industry in the United States turned a profit for the first time in its history (Ernst&Young, 2010). The development of the Finnish biotech industry is strongly dependent on innovation policy, both at national and European levels, as high risks and long development times set extreme financial challenges for the sector. 2008 was the first year the biotech industry in the United States turned a profit.

In international rankings, the Finnish innovation environment and education are rated among the best in the world. The Global Innovation Index published by INSEAD (2012) ranks Finland fourth among other developed nations. Finland's strengths were its political and legal environments, the number of researchers, gross expenditure on R&D, general infrastructure, cluster development, and patent applications. However, there are performance differences between industrial sectors. In particular, the forestry and information/computer technology (ICT) industries— the traditional pillars of the Finnish economy—have faced difficulties, as mobile manufacturing leader Nokia has lost market share in the smartphones business and the paper sector has experienced big structural changes due to production operations moving out of the country. New sources of growth are needed at the national level, and the analysis of emerging industries is increasingly relevant to the policy makers.

In innovation system research, innovation and the development of industries are based on complex interactions between firms and their environment. Innovation systems comprise structural components (actors, networks and institutions) and activities. They include not only economic properties but also social, cultural and institutional frameworks (Smith 2000). When studying rapidly changing innovation systems, it is insufficient to focus solely on the structural components and the interaction activities must also to be considered (Hekkert *et al.*, 2007). Mapping all activities within innovation systems is, however, not feasible due to the massive complexity inherent in the systems, so relevant activities must be identified—those that influence a system's ability to develop, diffuse and utilize innovations, *e.g.* R&D activities and efforts to link different actors (Liu and White 2001; Carlsson and Stankiewicz, 1991). Relevant activities have an effect on one or more system functions. Functions are key processes of innovation systems and their performance is necessary for the developments of the systems.

In the current paper, we examine the dynamics and functionality of the life sciences industry in Finland using a functional technological innovation system analysis approach. We describe the various actors, networks, and institutions within Finland and then map activities related to the system functions. We evaluate six functions: knowledge development and diffusion, entrepreneurial experimentation, influence on the direction of search, market formation, legitimation, and resource mobilization. From the activities, we identify several inducement and blocking mechanisms that affect the industry's development in Finland.

To illustrate the conditions and best practices of a very successful region, we analyze the life sciences industry within the San Francisco Bay Area as a representative technological innovation system. This illustration is presented before the results of the Finnish life sciences system. We do not make direct comparisons between these two systems because the San Francisco Bay Area system is delineated by regional borders and the Finnish one by national borders.

2 Theoretical framework

The innovation system framework consists of three components: actors, institutions, and networks (Carlsson and Stankiewicz, 1991). Innovation systems may be delineated by national borders (Nelson, 1993), regions (Cooke, 2001), sectors (Malerba, 2002) or technologies (Markard and Truffer, 2006). The overall goal of an innovation system is to develop, diffuse and utilize innovations. However, the interaction between various components is often not deliberate, causing conflicts and tensions in the dynamics of innovation systems (Bergek *et al.*, 2008, Bergek *et al.*, 2005).

Innovation systems often focus on the development of technology. However, social, cultural and institutional factors such as user practices, regulation, industrial networks, infrastructure and symbolic meaning also influence the development, diffusion and utilization of new products and services (Geels 2002). The nature of innovation systems is sometimes described as socio-technological (Berkhout *et al.*, 2004; Markard *et al.*, 2012). Whereas other innovation systems discuss mostly the factors that help reinforce existing technologies, technological innovation system studies analyze radically new socio-technological systems. Technological innovation system (TIS) literature has its theoretical grounds in sociology, science and technology studies, economics and management (Lovio and Kivimaa 2012). Recently, linkages have been formed between TIS scholars and futures studies scholars, who have found common ground in their long-term future orientation (Farla *et al.*, 2012) and interest in the actions of a wide range of different stakeholders and networks (Porter *et al.*, 2004). TIS analysis is particularly relevant to technological foresight due to the focus on technology (Andersen and Andersen 2012).

An analysis of TIS proceeds through three steps, illustrated in Figure 1. First, the structural components of the system have to be identified. Second, performances of the system functions are evaluated. This is carried out by identifying activities that have an effect on one or more of the system functions. Third, inducement and blocking mechanisms are identified from the results of the previous step. The recognition of these mechanisms provides a good starting point for policymakers who aim to promote the development of specific technologies.

TIS actors may be organizations (e.g., firms, universities, governmental bodies, etc.) or individuals. These actors interact through different forms of communication, exchange, co-operation, competition, and command (Malerba, 2002). Institutions are the "rules of the game": laws, technical standards, regulations, norms, routines, and shared expectations that guide and regulate the interactions and relations between actors (Edquist, 2005). Networks facilitate the transfer of tacit and explicit knowledge, enable access to resources, and shape the goals and expectations among members (Jacobsson and Johnson, 2000).

-----------------------FIGURE 1 HERE ----------------------------------

Figure 1. *Scheme of analysis*

The goal of technology policy is to select a desirable future and facilitate its realization (Grupp & Linstone, 1999). The TIS framework can be seen as a policy tool for promoting the developments of technological fields that are believed to have positive societal effects in the long term. Edquist (2005), Hekkert *et al.* (2007), Hillman *et al.* (2008) and Bergek *et al.* (2008) have proposed similar sets of functions which help in mapping out important activities within TIS. To function properly, all aspects of the innovation processes must be addressed. In this paper, we analyze the performance of the life sciences TIS via a set of six functions: knowledge development and diffusion, entrepreneurial experimentation, influence on the direction of search, market formation, legitimation, and resource mobilization[2]. These functions are described in the next subchapter.

The analysis of system functions helps locate inducement and blocking mechanisms in innovation systems. Inducement mechanisms promote the development of a TIS. These may be, for example, changes in relative prices favoring a certain technology or feedback from early users (Jacobsson & Johnson, 2000). Blocking mechanisms may be market failures arising from R&D uncertainty and the inappropriability and indivisibility of information (Nelson 1959; Arrow 1962). They also cover system failures related to infrastructures, institutions, networks and capabilities. Examples of these include poor ICT and science-technology infrastructure, incompatible legislation and regulation, lack of connections between firms, and inertia in firm management (Woolthuis *et al.*, 2005). Blocking mechanisms can be seen as innovation system bottlenecks. The goal of TIS analysis is to identify barriers to the development of emerging technological fields so that policy makers are able to design the most effective measures to promote the desired futures.

2.1 Innovation system functions

A TIS is fundamentally about the creation and diffusion of knowledge and information, indicating that various types of knowledge are required for a technological field to prosper. The development of the knowledge base of a system has several sources. Since different actors have access to different kind of knowledge, comprehensive networks are important. *Knowledge development and diffusion* comprises the breadth and depth of the knowledge base and the flow of knowledge between various actors (Bergek *et al.*, 2008). Borrás (2004) associates different components with different knowledge-related processes. Knowledge creation benefits from universities, the education system, testing laboratories, and research subvention schemes. Actors , such as technology transfer centers and bridging organizations, and the social and corporate conventions for the diffusion and share of knowledge play a significant role.

Schumpeter (1975) describes the nature of capitalism as “creative destruction” in which the market environment evolves by destroying old structures and giving birth to new ones. This evolution creates considerable uncertainty about the future. The best way to reduce the uncertainty is constant *entrepreneurial experimentation*, which consists of finding new business opportunities from emerging technologies and applications. The search process induces a social learning process into the whole system (Bergek *et al.*, 2008). Weak relationships between universities and firms are often considered as bottlenecks in TIS. Major business opportunities may remain unexploited because of insufficient scientific knowledge transfer (Lundvall and Borrás, 1997).

The search for innovation opportunities is assumed to be a costly process, and actors differ in their abilities to recognize and valuate promising opportunities. Numerous actors with different knowledge and skills are needed in the system in order to increase the chances of finding a feasible direction to pursue. The function of *influence on the direction of search* consists of the incentives for the relevant firms and organizations to join the network and the activities which direct the search within the system (*e.g.* choices between different competing technologies, applications, markets, business models) (Bergek *et al.*, 2008; Bergek *et al.*, 2005). According to Hekkert *et al.* (2007), the function refers to those activities that can positively affect the visibility and clarity of specific wants among technology users.

A functioning market is an essential part of innovation by providing a platform for entrepreneurial experimentation, creating an incentive for firm entry, and facilitating the diffusion of knowledge (Jacobsson and Bergek, 2011). The market embodies relationships between customers and producers, both of which are needed in the network. *Market formation* usually proceeds through three stages. First, products require a "protected space" or a niche, which acts as an "incubation room" in which actors form relationships and may learn and shape expectations about the new technology. Policymakers can support the growth of a new technology by providing subsidy schemes and investment grants, helping the technology cross the "valley of death" between research and market introduction (Bergek *et al.*, 2008; Geels, 2005; Raven and Geels, 2010). Niche markets may evolve into bridging markets with higher volumes and more actors and finally into mass markets that no longer need outside support to function (Schot *et al.*, 1994). Emerging technologies typically suffer from a low adoption rate, which is partly due to a lack of customer experiences. When a critical mass of customers has adopted the product or service, its diffusion curve "takes off" and it no longer needs outside support (Rogers, 1995).

Legitimation can be described as social acceptance and compliance with relevant institutions. Legitimation processes usually aim to adjust the institutional framework to support the development of the system better and to overcome the stigma of a new technology in the eyes of relevant stakeholders (Bergek *et al.*, 2008). Emerging technological systems usually compete with existing systems that try to defend their position and the related institutions. Often the best way to break through is to form advocacy coalitions with the actors in the sector and take concerted actions (Sabatier 1988; Weible 2007). Institutional weakness takes place when existing institutions are unsuitable and difficult to amend, and network weakness occur when few actors form political consortia to advocate their demands (Jacobsson and Bergek, 2011).

The viability of a technological system depends on the availability of required resources. The function *resource mobilization* concerns the allocation resources, including human capital (i.e., education and scientific knowledge in related fields), financial capital, and complementary assets (i.e., products, services and infrastructure) (Hekkert *et al*,. 2007; Bergek *et al.*, 2008). The availability of resources is necessary for all innovative activities and can be provided by government or venture capitalists (van Alphen, 2011).

3 Data and methodology

The data of the study consists of 33 in-depth qualitative interviews with practitioners and researchers. Interviews were conducted face-to-face when possible; otherwise by phone or email. All data was gathered during the year 2010. The interviewees, chosen with snowball sampling, include university professors, researchers, policymakers, consultants, R&D directors, senior executives, and entrepreneurs. The sectors of functional foods, drug development, diagnostics, biomaterials, bioinformatics, medical design and technology areas were included in the study. The interview questions, partly based on a previous study by Carleton (2009), were designed to elicit open-ended responses from participants. Questions were organized into four categories: regional changes, global and local collaboration and partnering, customers and users, and funding.

The data collected provides information about life sciences innovation systems located in two distinct regions. Nine of the interviews were conducted in the San Francisco Bay Area in the United States and the remaining 24 interviews were in Finland. We analyze the San Francisco Bay Area life sciences TIS to illustrate the conditions and best practices of a very successful region because it is considered the leading region in the world in the life sciences field (EUCE, 2009; Gittelman 2007). This illustration provides a complementary perspective to the later analysis of the Finnish life sciences TIS. Despite having roughly similar population sizes, the two regions are not directly comparable since the San Francisco Bay Area TIS is delineated by regional borders and the Finnish TIS by national borders. Since relevant actors, institutions, networks, and their dynamics are determined by the scope of the innovation system, the network functions and their fulfillment might point to activities of very different natures. The focus of this study is the analysis of the Finnish life sciences TIS, which is reflected in the number of the interviews and interview questions.

The biggest industrial sector within the Finnish interviews was diagnostics, whereas it was medical devices and technologies in the Bay Area interviews. The main questions were the same in both areas, and the interviews conducted in the San Francisco Bay Area are consistent with data available from other sources (e.g. newspapers, statistical information). All the interviews were recorded and transcribed. The interview transcripts were analyzed, and the frequencies of key concepts mentioned across interviews were recorded. The observations and conclusions drawn in this paper are based on key concepts mentioned in several interviews, reflecting widespread views in the sampling. In addition, the conclusions are supplemented by statistical data from various sources.

To further deepen our view of the Finnish life sciences field, a two-day foresight workshop was conducted in the spring of 2010 with representative members from the Finnish life sciences community. During the workshop, we gathered the participants' inputs on emerging insights, regional concerns, and promising opportunities for long-term success. The participants worked in groups and produced information on past, current, and future perspectives. The group work outcomes were documented through photographs and other means. The preliminary results of the interviews were used as background material for workshop discussions and explorations of industry visions. Issues arising from the interviews and workshop that were supported by the literature review were classified according to the TIS framework. Inducement and blocking mechanisms were identified from the data.

4 Results

4.1 San Francisco Bay Area

4.1.1 Structural components

Over 50 years in the making, the San Francisco Bay Area is known for its resilience to undergo economic changes and capitalize on emerging technologies. The life sciences sector is one of many industries that have benefited from the region's array of resources. The Bay Area provides a rich ecosystem with strong universities, funding capital, and diverse foreign talents—all of which spur local entrepreneurship and innovation. The Bay Area is home to four major research universities: University of California at Davis, University of California in San Francisco, University of California at Berkeley, and Stanford University.

Modern biotechnology has its roots in the Bay Area. In 1971, biotech was born in the Bay Area when Cetus Corporation was founded to develop new pharmaceutical drugs and techniques. Five years later, Genentech opened its doors. Genentech remains the largest biotech company in the region (BayBio, 2010). Today, Northern California has the largest cluster of life sciences companies in the United States with over 1300 companies and over 100,000 employees (ibid.). Although employment is relatively small in comparison with IT and service-related sectors, biotech and the life sciences are almost three times more concentrated in the Bay Area than in the rest of the nation.

Foreign-born talent also plays a critical role in regional growth. Professor AnnaLee Saxenian (2006) at the University of California at Berkeley has studied the growing international mobility of entrepreneurs. Skilled immigrants account for one third of the Bay Area's engineering workforce and are increasingly visible as entrepreneurs and investors. Two thirds of the region's foreign-born engineers come from Asia. Their global viewpoints and connections enrich the local culture and appetite for new ideas.

4. 1.2 Evaluation

The inducement and blocking mechanisms of the San Francisco Bay Area are illustrated in Figure 2. Arrows from the inducement mechanisms to the functions depict a positive relation between a mechanism and the performance of a function. The arrows from the blocking mechanisms depict negative relations between a mechanism and the performances of a function.

In the Bay Area, the development and diffusion of knowledge benefit from tight clustering. Skilled workers are concentrated in the region and the labor mobility is high. The workers create knowledge spillovers as they form relationships with each other and change jobs. Life sciences companies are located near top universities and research institutes. The university-industry relations are considered highly functional and have positively affected industrial success.

-----------------------FIGURE 2 HERE ---------------------------------

Figure 2. *Inducement and blocking mechanisms in the San Francisco Bay Area life sciences innovation system*

The Bay Area's TIS thrives in entrepreneurial experimentation. A critical mass of companies, universities, and successful entrepreneurs are concentrated in the area. Previous successes encourage risk-taking and promote the industry. Many people have previously established companies and are most likely to establish new companies or act as mentors to others. The availability of experienced entrepreneurs increases the stock of human capital and promotes the creation of new companies. In the figure, this is illustrated by arrows from the mechanism of business know-how to the functions of resource mobilization and entrepreneurial experimentation. The area has also succeeded in attracting lots of skilled employees and researchers which similarly increases the availability of human capital and boost the development of knowledge.

Access to venture capital is considered one of the main factors in the field's success. There are investors specializing in the biotech industry. The availability of risk capital loosens one of the most crucial constraints in entrepreneurial experimentation: the financial constraint. The domestic market is large and well-formed, and companies do not need to concern themselves with language and cultural differences, geographical distances, different legal frameworks, or company cultures. This is reflected in the good performance of the functions entrepreneurial experimentation and market formation. However, a concern was raised that the direction of search is strongly influenced by short-term profits (middle right arrow in Figure 2). Financiers tend to invest in safe projects that may not be the most innovative ones. This may be an indicator of the dominance of market-pull over technology-push forces in the development of technology.

However, the American healthcare system is quite fragmented. Distinct and often competing entities are responsible for the financing and delivery of healthcare. Each of these units has their own objectives, capabilities, and obligations (Cebul *et al.*, 2008), which makes conducting clinical studies difficult as there is no access to clinical samples with full treatment and outcome histories. The shortage in infrastructure has a decreasing effect on the function knowledge development and diffusion (top right arrow in Figure 2). The U.S. Food & Drug Administration agency (FDA) has implemented complex clinical trial requirements that complicate the execution of R&D projects. This mismatch between R&D needs and institutional framework is depicted by the bottom right arrow in Figure 2.

4.2 Finland

4.2.1 Actors and networks

Several actors serve important roles in the Finnish life sciences innovation system. In this section, we concentrate on the actors that are the most relevant based on the interviews. The actors are compiled in Figure 3. According to Finnish Bio-Industries, in 2005 there were 212 firms in the biotechnology industry employing over 8000 people in Finland. Around 70 percent of these companies conducted R&D activities (van Beuzekom and Arundel, 2009). Biotechnology is concentrated on five regions within the country: Helsinki, Turku, Tampere, Kuopio, and Oulu. In these regions, universities and biocenters are important elements (von Blankenfeld-Enkvist *et al.*, 2004). In addition to the universities, several research institutes and technology incubators are located in these areas.

The Finnish Ministry of Employment and the Economy oversees Finland’s technology and innovation policy, while the Finnish Ministry of Education and Culture is responsible for the science policy. Key issues are coordinated by the Research and Innovation Council, chaired by the Prime Minister. At the regional level, the national technology policy is implemented by the Centers for Economic Development, Transport and the Environment. The Foundation for Finnish Inventions (FFI) screens and evaluates inventions and innovative ideas generated by private persons and startup companies and helps to develop these ideas into businesses.

-----------------------FIGURE 3 HERE ---------------------------------

Figure 3. *Actors in the Finnish life sciences innovation system*

In Finland, Tekes (the Finnish funding agency for technology and innovation) is the main public funding organization for applied research, development and innovation, and was seen as a key strength in the Finnish innovation environment in our study. Another big public financier, the Academy of Finland, concentrates more on funding basic research in academia.

Sitra, the Finnish Innovation Fund, is an independent public foundation under the auspices of the Finnish Parliament. Sitra's activities are financed by the yields from its endowment capital and the return on its venture capital investments. Sitra was actively investing in biotech until the first years of 2000; however, in 2004, it withdrew, leaving a big gap in VC funding in the field (Luukkonen and Palmberg, 2007).

HealthBIO is a "Competence Cluster" for health-related biotechnology within the fixed term special governmental Centre of Expertise Programme. This cluster aims to build the international competitiveness of the Finnish biotechnology. Finpro is a globally operating service organization. Its main objective is to support Finnish firms in the internationalization of their operations.

4.2.2 Institutions

Laws, standards and regulations play an important role in the life sciences innovation environment. Many laws and regulations are based on EU directives, but some national institutions have a strong effect on the emergence and development of the industrial sector. Institutions related to university-industry relationships and taxation issues were seen to be particularly important by the interviewees.

The university-industry relationships have been crucial for the emergence of the life sciences industry in Finland. Legal and structural changes related to this relationship were highly central, especially three changes. In chronological order, the first change is the University Inventions Act from January 2007. The Act's objective is to promote technology transfer from research to industry. The second change is the establishment of the Strategic Centers for Science, Technology and Innovation (Finnish acronym SHOK). SHOKs are new public-private partnerships, and their main goal is to promote collaboration between universities, research institutes, and companies, and to facilitate the creation of radical innovations. The SHOK operating in the life sciences sector was founded in April 2009. The third change is the new Universities Act which came into force in the beginning of 2010. The objective of the renewal is to give universities a more autonomous position in terms of financing and overall management, and to offer universities better premises to fulfill their three central assignments: research, education and societal interaction.

In addition to the university-industry relationships, taxation issues were considered critical in fostering life sciences innovations. Taxation has an important role in creating a growth-friendly environment in which venture capitalists, business angels and companies feel comfortable in investing. In 2005, 70 percent of OECD member countries, excluding Finland, had tax incentives for R&D investments (EC, 2006). A working group of the Finnish Ministry of Employment and the Economy (MEE) has actually proposed the introduction of an R&D tax incentive scheme in Finland, but it is still under evaluation. The public R&D money for Finnish companies as well as the tax incentives have stayed below the average of OECD countries (OECD, 2010).

4.2.3 Functions

a) Knowledge development and diffusion

Based on our data, the biggest strength of the Finnish life sciences innovation system is the high level of the basic research, especially clinical research and biomedical research. This view is supported by statistical data. In a national ranking of clinical medicine research in 1999-2009, Finland was the top country on citations per research paper (Thomson Reuters, 2010). In the biotech field, Finland has stayed above the European average in terms of publications and citation indicators (Reiss and Dominiguez Lacasa, 2005). The high level of basic research improves the performance of the function of knowledge development and diffusion. It also guides the direction of opportunity search since existing specialized knowledge bases are natural starting places for searches for new technologies (Nelson and Winter, 1982).

Public policies play an important role in supporting networking and the diffusion of knowledge. Tekes and EU funding require university-industry collaboration, which facilitates networking, partnering, and gaining important knowledge from the field. However, collaboration works sub-optimally because academic projects are guided more by an opportunity to acquire research funding than a genuine interest in collaboration, thus partly preventing additional knowledge diffusion. Public support is nevertheless a key factor in the development and diffusion of knowledge.

Changes in Finnish innovation policy have brought academia and industry closer to each other, and the resulting attitudes and atmosphere have gradually changed more positively towards commercialization. Companies would like to be involved in university projects already at the planning stage, but researchers in the universities worry that a closer university-industry partnership will shift the focus excessively towards applied research. Time will tell how institutional changes in the university-industry relationships will alter the situation.

The role of technology transfer offices and innovation services in promoting the commercialization of university inventions is crucial. The low maturity of university inventions sets challenges, implying a need for specific organizations to assure the development of the inventions to a more mature state. The technology-push approach typical of high-tech sectors leads to lack of customer orientation, which was mentioned as one of the weaknesses of the sector.

b) Entrepreneurial experimentation

Roughly 200 companies, including consulting companies and distributors, operate in the biotech industry in Finland. Around 25 percent of these operate in diagnostics, 25 percent in pharmaceutics, 10 percent in biomaterials, and 5 percent in bioinformatics (TEM, 2009). Finland has a particularly strong competence in industrial enzymes. The number of biotech firms grew sharply through the late 1990s but then stagnated (Hermans *et al.*, 2005).

In the life sciences sector, diagnostics and drug discovery stand out as the most important branches. The diagnostics sector, with a relatively long history, consists of around 30 companies and €370 million yearly net sales of which €330 million come from exports (Invest in Finland, 2011). In addition, the big multinational companies Thermo Fisher Scientific and Perkin Elmer have facilities through acquisitions in Finland. In this study, diagnostics was regarded as the most dynamic sector. The pharmaceutical sector is challenging due to extremely long development times, high development costs, and the absence of big Finnish pharma companies. In contrast to nations such as Sweden and Denmark, Finland has never developed a strong pharmaceutical industry, which puts it in a weak position with few skilled employees and relevant business know-how. However, Finland is strong in clinical and biomedical research, but has not been able to create a thriving industry yet in these fields. In the pharmaceutical sector, there are some domestic producers, and Orion is the biggest company with nearly €850 million annual net sales. Multinational companies Bayer and Santen also have production facilities in Finland (Espicom, 2011). The total pharmaceutical sales in Finland were roughly €2 billion with wholesale prices in 2011 (Pharma Industry Finland, 2012).

-----------------------FIGURE 4 HERE ---------------------------------

Figure 4. *Inducement and blocking mechanisms in the Finnish biotech innovation system, constructed from the Finnish interviews*

The number of established companies in the bio sector[3] has declined from 50 to 35 (a 30 percent decrease) in the 5-year-period of 2002-2006 to 2007-2011. Around 60 percent of the new companies in these branches are small service providers. The sizes of Finnish life sciences companies are quite modest and around 30 percent of them are one-person businesses (personal communication by Kai Lahtonen, Senior Advisor). The growth of the companies is slow, and high-growth enterprises are largely missing. University researchers who establish businesses lack entrepreneurial experience and often fail to utilize know-how from other sectors. This is depicted by an arrow from the blocking mechanism of business know-how to the function entrepreneurial experimentation in Figure 4. During the last few years, universities have focused on building mechanisms and structures to support entrepreneurial activities and exploit university-based inventions better. These activities are largely at the development stage. Finnish companies are characterized by risk-aversion and low ambition which restricts their growth (Murray, 2011).

Distant location and the small size of the domestic market force Finnish companies to go abroad very early without having a chance to grow and learn in a familiar environment. Lack of resources inhibits networking and global partnering which are necessary to create global value chains. Public funding is important but cannot account for all of the industry’s needs. Venture capital is poorly available which disturbs the formation and growth of the companies. Entrepreneurial experimentation is thus induced by public support and hindered by the size of domestic market, lack of global networks and availability of risk capital.

c) Influence on the direction of search

The life sciences sector in Finland is strongly guided by technology-push mechanisms. New products originate from scientific developments and the lack of customer-orientation is considered a weakness. Companies find it hard to acquire knowledge of the demand factors and cannot direct their search with respect to it.

Public funding organizations and their emphases influence the direction of research and development. At the beginning of the last decade, the sector was booming and it was hoped to become a new pillar of the Finnish economy. Attitudes however changed radically and the amount of financial support decreased. Uncertainty about the continuity of funding has a strong effect on the attractiveness of the industry. Another problem concerns the focusing of research efforts. Based on our study, there is a need to focus efforts on a few substantial projects instead of giving little to everyone. Furthermore, the companies should join their forces to be able to increase their competence, offering and visibility. Currently, the actors in the field are too scattered. There is too little collaboration for the actors to be able decide on a concerted direction to pursue and gain synergy benefits from joint activities (top right arrow in Figure 4).

d) Market formation

The know-how and business competence are gradually accumulating, as the life sciences industry is becoming more mature. Still, it seems that Finland is not an optimal environment for the companies to prosper. In the absence of long-term funding, companies are forced to find other sources of income before the actual product is on the market. That means new innovative business models, virtual companies, combining service and product development, *etc*. Also, the bigger players have not taken a role as active in the market formation as expected

Finnish actors are largely disconnected from the relevant networks in the global markets. From the perspective of the Finnish life sciences sector, market formation means the integration into the global market. Small biotech companies need partners and strategic alliances to share risk and access financial resources (Amir-Aslani and Negassi, 2006). This view was supported in our study. Small companies often lack skills and resources to form relationships in order to penetrate the foreign market. The Finnish financiers may not be able to help as they are not specialized in the life sciences field. Language and cultural differences, geographical distance and legal frameworks set further challenges in partnering. Attracting global companies to Finland requires policy support and actions, *e.g.* the development of tax incentives, funding instruments, and national patent pools. Small size of the domestic market forces the firms to aim to penetrate global markets. This would require strong global partners which are currently missing.

e) Legitimation

The legitimation of the sector faced a downturn in mid-2000 when Sitra withdrew from the capital markets. Sitra’s decision was based on unreasonable expectations towards the development of the biotechnology industry. In its footsteps, other investors also started to reconsider their investments. Recently, the appeal of the sector has been quite low among the investors. Actors in the field are concerned that financiers and the public sector fail to understand the special features and demands of the sector and that the industry has not gained as much positive publicity as deserved. Negative publicity in Finnish media may have an unfavorable influence on foreign investors. On the other hand, public attitudes towards research and biotechnology are in general positive, promoting the adoption of new techniques and innovations among users and customers (Lähteenmäki, 2002).

f) Resource mobilization

Finland is one of the most research-intensive countries in the world. Finnish national R&D expenditure is 3.9% of GDP. 70% of the R&D investments are covered by the private sector and 30% by the public sector. The private sector figures are however dominated by the ICT sector and total R&D expenditures in the biotechnology sector[4] are pretty modest: 116 million PPP$ in 2007. In comparison, the number was 486 million PPP$ in Sweden, 922 million PPP$ in Switzerland (2008), and 302 million PPP$ (2009) in Ireland. Average R&D spent per a dedicated biotechnology firm was 0.79 million PPP$ in Finland, compared with 4.64 in Sweden and 7.92 million PPP$ in US, reflecting the small size of the companies (van Beuzekom and Arundel, 2009).

Based on the interviews, Finland stands out with its good educational system, high-quality basic research, good infrastructure and internationally recognized technological competence. In addition, the public health care system provides an advantage over many other countries. The Finnish health care system has comprehensive patient registers, which may increase the potential of clinical studies. The law on establishing a bio bank for blood and tissue samples in Finland is under preparation and will probably come into effect at the start of 2013. On the other hand, resource mobilization is hindered by the weak venture capital market and poor public image among investors resulting from realized political risk as Sitra drastically decreased its funding in 2004.

4.2.4. Mechanisms

We identified four inducement mechanisms and six blocking mechanisms in the Finnish life sciences innovation system. These are illustrated in Figure 4. Although the relative strengths of different mechanisms are difficult to assess, the figure suggests that public actions of different kinds (the upkeep of infrastructure, funding, education) and accumulated research capabilities provide a strong basis for knowledge development and diffusion. This is the main strength of the TIS. The industry development is hindered by several system failures. First of all, there are network failures at two levels: i) lack of domestic collaboration and ii) lack of global contacts. On the national level, the actors are deprived from the synergy benefits of collaboration. The main problems are the difficulties in internationalization. The firms need contacts to penetrate global markets. This issue is worsened by the small size of the domestic market that forces the firms to go abroad at very early stages. Firms also suffer from a capabilities' failure: the trouble in market penetration is compounded by the absence of business know-how. Finally, there is an institutional failure in the form of poor public image set off by the public innovation fund Sitra by its withdrawal from the capital markets.

5 Discussion

This paper describes the Finnish life sciences industry in the framework of a technological innovation system. It is based on qualitative interviews and a two-day workshop. Complementary statistical data has been searched from various sources. The statistical data supports our study well, despite the fact that no clear and widely accepted definition exists the for life sciences industry, so relevant data about the sector was often hard to find and then compare on similar terms.

In international comparison studies, the Finnish innovation environment has been rated as one of the best in the world. One of the often stated Finnish strengths is the high quality of education, especially the country's high rankings in the PISA surveys (e.g., OECD Programme for International Student Assessment). The Finnish educational policy has aimed at equity in education, student performance is largely unrelated to the schools, and the teachers are highly qualified professionals (Niemi, 2009).

The university-industry relationship plays a crucial role in the development of the life sciences sector. Interviewees were concerned about strategic decisions in reducing basic research funding and also university-industry relationships that guide this research increasingly in the applied direction. Despite these misgivings, several studies suggest that the growing number of university-industry partnerships has had no negative effect on the quantity and quality of basic research (Geuna and Nesta, 2006; Louis *et al.*, 2001; Poyago-Theotoky *et al.*, 2002; Zucker and Darby, 1996).

Because of its ability to give birth to very successful life sciences clusters, particularly the San Francisco Bay Area, the innovation environment in the United States provides an interesting point of comparison for the Finnish TIS. Owen-Smith *et al.* (2002) argue that the strengths of the innovation system in the US result from an institutional set-up which supports networking and collaboration. In the US, public research organizations and small firms collaborate across different regions and stages of the innovation process. This generates robust networks which tie public and private actors tightly together and make the commercialization of academic research easy. Furthermore, the US university system has a long history in conducting research with major impacts on technological development and industrial performance. The growing commercialization of academic research has its roots in the technology transfer offices created by American universities and in the Bayh-Dole Act of 1980which allowed the commercial use of university research (Powell *et al.*, 2007). It has been stated that the relationship between the university scientists and the industry is closer in the US than anywhere else. This is regarded as one of the reasons why the US has a leading position in the life sciences field (Dalpé, 2003). In Europe, the academic and business goals have been more apart from each other. The US way has so far proved more successful in science and technology based industries.

According to Niosi (2011), the biotechnology sector does not reach its full potential in many countries because of insufficient co-evolution between technology and institutions. The scientific development is so fast that the institutional design may fall behind and get locked into inferior practices and mechanisms which do not support the industry's needs optimally. For example, it is easier for academics to found start-ups while retaining their academic posts in the US than in Europe. Moreover, the European patent system is less receptive to biotechnology than that of the US.

University-industry relationships have a significant role in the life sciences industry. Even though there has been a great progress in Finland in the last two decades, there is still room for improvement. Universities have recently started to show more interest towards the commercialization of their research. Together with the increasing demand for industry-commissioned research, there is a growing need for new mechanisms and concepts for improved university-industry collaboration. Licensing, establishing start-ups and selling patents is just part of the solution. Continuous development of technology transfer offices at universities and research institutes is crucial and could benefit from national joint efforts, *e.g.* shared resources between universities and patent pools. Another challenge to be solved is how universities could be supported in developing their inventions into such mature concepts that the companies would become interested in them. There have been few institutional changes lately. Their impacts will be perceived in the near future.

Reiss and Dominiguez Lacasa (2008) compare the knowledge base and the commercialization abilities of biotechnology innovation systems in 18 European countries. They create composite indicators from different data sources to evaluate the levels of research and commercialization. The knowledge base indicator combines the numbers of biotechnology publications and citations relative to population. Finland places third in publications and seventh in citations. According to the knowledge indicator based on these values, the scientific performance of Finland in the field is the fifth best among 18 countries, well over the median value. This is in accordance with our results. In their study, the commercialization indicator is calculated from the number of patents, the number of firms and the amount of venture capital. All values above are relative to population. Finland places below sample average in patents and venture capital which corresponds our findings. However, because of the high number of firms, the overall indicator places Finland at the fourth place in commercialization skills. This conflicts our findings. We discovered that the Finnish biotechnology sector faces significant difficulties in the commercialization phase. This view is also supported by the low number of patents, which usually play an important role in high technology industries. The inconsistency is probably due to the use of the number of firms as an indicator for commercialization abilities. Despite the high number of firms, the total number of employees in the sector remains low in Finland. 50 new life sciences firms were founded between 2002 and 2006. In 2010, these employed only 379 people. The corresponding numbers for the period 2007-2011 are 35 new firms and 143 employees (personal communication, Kai Lahtonen, Senior Advisor). The small size of the firms makes their quantity an unreliable indicator for successful commercialization. Results from a survey by Renko *et al.* (2005) support our findings that the Finnish life sciences innovation system's focus is on research while the commercialization abilities are less developed.

The lack of customer focus was blamed in the Finnish life sciences industry. Even though some understanding about the customer's need and processes are needed, the existing structures especially in larger companies and a strong market orientation towards a particular sector may actually prevent radical product innovations (Christensen, 1997; Renko *et al.*, 2005) in biotechnology or life sciences sectors.

Because of the great differences in the institutional frameworks, capabilities and networks between Finland and the US, it is not likely that Finland could or should try to create life sciences clusters similar to the San Francisco Bay area. Our results suggest that innovation policy should focus on removing bottlenecks specific to the Finnish TIS and maintaining its existing strengths. The main targets of action should be supporting commercialization of innovations, internationalization of the firms, promoting the creation of venture capital markets and encouraging domestic collaboration and smart specialization. Relevant policy measures for promoting collaboration, networking and vision building include R&D subsidies for collaborative projects and joint ventures, seminars, strategic conferences and scenario workshops

6 Conclusions

In international comparison studies, the Finnish innovation environment has been rated as one of the best in the world. Technological innovation system analysis exposes a comprehensive and detailed picture of the environment from the perspective of a single technology field. In this study we examined the technological innovation system of the life sciences field in Finland to reveal the technology-specific strengths and weaknesses that may be hidden in data aggregated from many sectors.

According to our results, the Finnish life sciences field benefits from top-level basic research. It has, however, difficulties in turning scientific advances into commercially successful products and services. This hinders the formation of a thriving industry. Scarce venture capital, limited commercialization experience, small market size, scattered actors, distant location, and weak global networking are blocking mechanisms that hamper the development of the field. These mechanisms require special attention from policymakers.

Notes

1. Biotechnology: OECD definition: "The application of science and technology to living organisms, as well as parts, products and models thereof, to alter living or non-living materials for the production of knowledge, goods and services."
2. Bergek *et al.*, (2008) present also a seventh function*, the development of positive external economies*, which deals with synergy benefits such as pooled labor markets, availability of specialized goods and knowledge spill-overs, which arise as the TIS grows and may affect all of the other functions. We have omitted this function from our analysis as we believe the externalities may be discussed in the context of the other functions.
3. Drug development, diagnostics, biomaterials, pre-clinical and clinical service providers, and consulting companies in this case.
4. Biotechnology R&D firms: firms that perform biotechnology R&D.

References

Amir-Aslani, A. and Negassi, S. (2006), “Is technology integration the solution to biotechnology's low research and development productivity?”, *Technovation*, Vol. 26 No. 5-6, pp. 573-82.

Andersen A.D. and Andersen P.D. (2012), “Innovation-system foresight. Explicating and systemizing the innovation-system foundations of foresight and exploring its implications”, DTU Management Engineering, Technical University of Denmark.

Arrow, K. (1962), “Economic Welfare and the Allocation of Resources for Invention”, in U-N Bureau (Ed.), *The Rate and Direction of Inventive Activity: Economic and Social Factors*, NBER, pp. 609-26.

BayBio (2010), “BayBio: Northern California's Life Science Association”, available at http://www.baybio.org/ (accessed 13th January 2011).

Bergek, A., Jacobsson S., Carlsson, B., Lindmark, S. and Rickne, A. (2005), “Analyzing the dynamics and functionality of sectoral innovation systems - a manual” presented at the DRUID Tenth Anniversary Summer Conference, June 27-29 2005, Copenhagen, Denmark.

Bergek, A., Jacobsson S., Carlsson, B., Lindmark, S. and Rickne, A. (2008), “Analyzing the functional dynamics of technological innovation systems: A scheme of analysis”, *Research Policy*, Vol. 37, No. 3, pp. 407-29.

Berkhout, F., Smith, A. and Stirling, A. (2004), “Socio-technological regimes and transition contexts”, in Elzen, B., Geels, F.W. and Green, K. (Eds.), *System Innovation and the Transition to Sustainability*. Edward Elgar, Cheltenham, pp. 48-77.

Borrás, S. (2004), “System of innovation theory and the European Union”, *Science and Public Policy*, Vol. 31, No. 6, pp. 425-33.

Carleton, T. (2009), *The Bay Area's Role in Global Innovation Networks. Bay Area Science and Innovation Consortium (BASIC).*

Carlsson, B. and Stankiewicz, R. (1991), On the nature, function and composition of technological systems. *Journal of Evolutionary Economics*, Vol. 1, No. 2, pp. 93-118.

Cebul, R.D., Rebitzer, J.B., Taylor, L.J. and Votruba, M.E. (2008) “Organizational Fragmentation and Care Quality in the US Healthcare System”, *The Journal of Economic Perspectives*, Vol. 22, No. 4, pp. 93-113.

Christensen, C.M. (1997), *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail*, Harvard University Press, Boston.

Cooke, P. (2001), “Regional Innovation Systems, Clusters, and the Knowledge Economy”, *Industrial and Corporate Change*, Vol. 10, No. 4, pp. 945-74.

Dalpé, R. (2003), “Interaction between public research organizations and industry in biotechnology”, *Managerial and Decision Economics*, Vol. 24, No. 2-3, pp. 171-85.

EC (2006), *Promoting innovation by tax incentives: A review of strategies and their importance to biotech growth*, European Comission.

Edquist, C. (2005), “Systems of Innovation: Perspectives and Challenges”, in Fagerberg, J., Mowery, D.C. and Nelson, R.R. (Ed.), *The Oxford Handbook of Innovation*. Oxford University Press, New York, pp. 181-208.,

Ernst&Young (2010), *Beyond Borders Global Biotechnology Report 2010*, available at http://www.ey.com/Publication/vwLUAssets/Beyond-borders-2010-EN/$File/Beyond-borders-2010-EN.pdf (accessed 13th January 2011).

Espicom (2011), *The Outlook for pharmaceuticals in northern Europe*.

EUCE (2009), *Life Sciences and Biotechnology: The Transatlantic Divide*, The European Union Center of Excellence of the University of North Carolina at Chapel Hill, available at http://www.unc.edu/depts/europe/business_media/businessbriefs/Brief0904-biotech.pdf/ (accessed 31 October 2012)

Farla, J., Markard, J., Raven, R. and Coenen, L. (2012), ”Sustainability transitions in the making: A closer look at actors, strategies and resources”, *Technological Forecasting and Social Change*, Vol. 79, No. 6, pp. 991-8.

Geels, F.W. (2002), “Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case study”, *Research Policy*, Vol. 31, No. 8-9, pp. 1257-74.

Geels, F.W. (2005), “The dynamics of transitions in socio-technical systems: A multi-level analysis of the transition pathway from horse-drawn carriages to automobiles (1860-1930)”, *Technology Analysis and Strategic Management*, Vol. 17, No. 4, pp. 445-76.

Geuna, A. and Nesta, L.J.J. (2006), ”University patenting and its effects on academic research: The emerging European evidence”, *Research Policy*, Vol. 35, No. 6, pp. 790-807.

Gittelman, M. (2007), “Does Geography Matter for Science-Based Firms? Epistemic Communities and the Geography of Research and Patenting in Biotechnology”, *Organization Science*, Vol. 18, No. 4, pp. 724-741.

Grupp, H. and Linstone, H.A. (1999), “National Technology Foresight Activities Around the Globe: Resurrection and New Paradigms”, *Technological Forecasting and Social Change*, Vol. 60, No. 1, pp. 85-94.

Haeussler, C. (2011), “The Determinants of Commercialization Strategy: Idiosyncrasies in British and German Biotechnology” *Entrepreneurship Theory and Practice*, Vol. 35, No. 4, pp. 653-81.

Hekkert, M.P., Suurs, R.A.A., Negro, S.O. and Smits, R.E.H.M. (2007), “Functions of innovation systems: A new approach for analysing technological change”, *Technological Forecasting and Social Change*, Vol. 74, No. 4, pp. 413-32.

Hermans, R., Kulvik, M. and Tahvanainen, A.J. (2005), *ETLA 2004 Survey on the Finnish Biotechnology Industry*. Discussion Papers. ETLA.

Hillman, K.M., Suurs, R.A.A., Hekkert, M.P. and Sandén, B.A. (2008) “Cumulative causation in biofuels development: a critical comparison of the Netherlands and Sweden”, *Technology Analysis & Strategic Management*, Vol. 20, No. 5, pp. 593-612.

INSEAD (2012), “Global Innovation Index 2012”, available at: http://www.globalinnovationindex.org/gii/ (accessed 23 October 2012).

Invest in Finland (2011), *IVD Diagnostics Tests*.

Jacobsson, S. and Bergek, A. (2011), “Innovation system analyses and sustainability transitions: Contributions and suggestions for research”, *Environmental Innovation and Societal Transitions*, Vol. 1, No. 1, pp.41-57.

Jacobsson, S. and Johnson, A. (2000), “The diffusion of renewable energy technology: an analytical framework and key issues for research”, *Energy Policy*, Vol. 28, No. 9, pp. 625-40.

Liu, X. and White, S. (2001), “Comparing innovation systems: a framework and application to China’s transitional context”, *Research Policy*, Vol. 30, No. 7, pp. 1091-114.

Louis, K.S., Jones, L.M., Anderson, M.S., Blumenthal, D. and Campbell, E.G. (2001), “Entrepreneurship, secrecy, and productivity: A comparison of clinical and non-clinical life sciences faculty”, *The Journal of Technology Transfer*, Vol. 26, No. 3, pp.233-45.

Lovio, R. and Kivimaa P. (2012), “Comparing Alternative Path Creation Frameworks in the Context of Emerging Biofuel Fields in the Netherlands, Sweden and Finland”, *European Planning Studies*, Vol. 20, No. 5, pp. 773-90.

Lundvall, B.-Å. and Borrás, S. (1997), *The globalising learning economy: Implications for innovation policy*. DG XII, Commission of the European Union.

Luukkonen, T. and Palmberg, C. (2007), “Living up to the Expectations Set by ICT? The Case of Biotechnology Commercialisation in Finland”, *Technology Analysis & Strategic Management*, Vol. 19, No. 3, pp. 329-49.

Lähteenmäki, R. (2002), “Finnish biotechnology–built on solid foundations”, *Nature Biotechnology*, Vol. 20, No. 5, pp. 437-40.

Malerba, F. (2002), “Sectoral systems of innovation and production”, *Research Policy*, Vol. 31, No. 2, pp. 247-64.

Markard, J. and Truffer, B. (2006), “Innovation processes in large technical systems: Market liberalization as a driver for radical change?”, *Research Policy*, Vol. 35, No. 5, pp. 609-25.

Markard, J., Raven, R. and Truffer, B. (2012), “Sustainability transitions: An emerging field of research and its prospects”, *Research Policy*, Vol. 41, No. 6, pp. 955-67.

Murray, G. (2011), “A Policy Response to the ‘Finnish Paradox’”. In TEM (Ed.) *Kasvuyrityskatsaus 2011*, Unigrafia Oy, Helsinki, pp. 38-45.

Nelson, R.R. (1959), 'The Simple Economics of Basic Scientific Research", *Journal of Political Economy*, Vol. 67, No. 3, pp. 297-306.

Nelson, R.R. (1993), *National Innovation Systems: A Comparative Analysis*, Oxford University Press, Cary, NC.

Nelson, R.R. and Winter, S.G. (1982), *An Evolutionary Theory of Economic Change*, The Belknap Press of Harvard University Press, Cambridge.

Niemi, H. (2009), "Why Finland on the top? Reflections on the reasons for the Pisa success" presented at the 3rd Redesigning Pedagogy International Conference, June 2009, Singapore.

Niosi, J. (2011), "Complexity and path dependence in biotechnology innovation systems", *Industrial and Corporate Change*, Vol. 20, No. 6, pp. 1795-826.

OECD (2010), *Measuring Innovation: A New Perspective, OECD, Paris based on NESTI 2009 R&D tax incentives questionnaire*.

Owen-Smith, J., Riccaboni, M., Pammolli, F. and Powell, W.W. (2002), "A Comparison of U. S. and European University-Industry Relations in the Life Sciences", *Management Science*, Vol. 48, No. 1, pp. 24-43.

Pharma Industry Finland (2012), "Statistics and Reports", available at: http://www.pif.fi/frontpage/satistics_and_reports/ (accessed 21 September 2012).

Porter, A.L., Ashton, W.B., Clar, G., Coates, J.F., Cuhls, K., Cunningham, S.W., Ducatel, K., Van der Duin, P., Georgehiou, L., Gordon, Linstone, H., Marchau, V., Massari, G., Miles, I., Mogee, M., Salo, A., Scapolo, F., Smits, R. and Thissen, W. (2004), "Technology futures analysis: toward integration of the field and new methods", *Technological Forecasting and Social Change*, Vol. 71, No. 3, pp. 287–303.

Powell, W.W., Owen-Smith, J. and Colyvas, J.A. (2007), "Innovaton and Emulation: Lessons from American Universities in Selling Private Rights to Public Knowledge", *Minerva*, Vol. 45, No. 2, pp. 121-42.

Poyago-Theotoky, J., Beath, J. and Siegel, D.S. (2002), "Universities and fundamental research: reflections on the growth of university-industry partnerships", *Oxford Review of Economic Policy*, Vol. 18, No. 1, pp. 10-21.

Raven, R.P.J.M. and Geels, F.W. (2010), "Socio-cognitive evolution in niche development: Comparative analysis of biogas development in Denmark and the Netherlands (1973-2004)", *Technovation*, Vol. 30, No. 2, pp. 87-99.

Reiss, T. and Dominiguez Lacasa, I. (2005), *Indicators for benchmarking biotechnology innovation policies*. OECD.

Reiss, T. and Dominiguez Lacasa, I. (2008), "The performance of European countries in biotechnology: how does Europe compare to the USA?", *International journal of Biotechnology*, Vol. 10, No. 4, pp. 303-26.

Renko, M., Carsund, A., Brännback, M. and Jalkanen, J. (2005), “Building market orientation in biotechnology SME's: balancing scientific advances”. *International Journal of Biotechnology*, Vol. 7, No. 4, pp. 250-68.

Rogers, E.M. (1995), *Diffusion of Innovations*, The Free Press, New York.

Sabatier, P.A. (1988), “An advocacy coalition framework of policy change and the role of policy-oriented learning therein”, *Policy Sciences*, Vol. 21, No. 2, pp. 129-68.

Saxenian, A.L. (2006), *The New Argonauts: Regional Advantage in a Global Economy*, Harvard University Press, Cambridge, MA.

Schot, J., Hoogma, R. and Elzen, B. (1994), “Strategies for shifting technological systems: the case of automobile system”, *Futures*, Vol. 26, No. 10, pp. 1060-76.

Schumpeter, J.A. (1975), *Capitalism, Socialism & Democracy*, Harper & Row, New York.

Smith, K. (2000), “Innovation as a Systemic Phenomenon: Rethinking the Role of Policy”, *Enterprise & Innovation Management Studies*, Vol. 1, No. 1, pp. 73-102.TEM (2009), *Bioteknologia 2020 – hyvinvointia suomalaisille, Linjaukset bioinnovaatioiden hyödyntämiseksi*, Ministry of Employment and the Economy, Finland.

Thomson Reuters (2010), *Thomson Reuters Essential Science Indicators SM database*.

van Alphen, K. (2011), *Accelerating the Development and Deployment of Carbon – An Innovation System Perspective*, Uitgeverij BOXPress, Oisterwijk.

van Beuzekom, B. and Arundel, A. (2009), *OECD Biotechnology Statistics 2009*, OECD.

von Blankenfeld-Enkvist, G., Brännback, M., Söderlund, R. and Petrov, M. (2004), *OECD Case Study on Innovation:The Finnish Biotechnology Innovation*, Innomarket, Turku School of Economics and Business Administration, Turku.

Weible, C. (2007), “An Advocacy Coalition Framework Approach to Stakeholder Analysis: Understanding the Political Context of California Marine Protected Area Policy”, *Journal of Public Administration Research and Theory*, Vol. 17, No. 1, pp. 95-117.

Woolthuis, R.K., Lankhuizen, M. and Gilsing, V. (2005), “A system failure framework for innovation policy design”, *Technovation*, Vol. 25, No. 6, pp. 609-19.

Zucker, L.G. and Darby, M.R. (1996), “Star scientists and institutional transformation: Patterns of invention and innovation in the formation of the biotechnology industry”, in *Proceedings of the National Acad Sciences USA*, 93, pp. 12709-16.