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SUSTAINABLE BIOTECHNOLOGY DEVELOPMENT

– New Insights into Finland

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Preface

The present book condenses the essence of ETLA's research project *"The biotechnology industry as part of the Finnish innovation system"* financed by Tekes. The project has resulted thus far in eight journal articles reprinted in this book, a dissertation for the Helsinki University of Technology, a Master's thesis for the Helsinki School of Economics, an edited book published in Finnish and about thirty discussion papers and other articles.

The rapid emergence of new science-based entrepreneurship related to biotechnology necessitates the evaluation of potential niches that the Finnish biotechnology sector could profitably focus on whilst developing products with commercial potential. Moreover, the competence base must be sufficiently large to generate the critical mass necessary for spawning successful products and services. This book looks at the preconditions for turning research into commercial products from the standpoint of the competence base underlying such a critical mass by:

1) utilising international trade analysis to identify the most competitive biotechnology-based industrial clusters (Chapters 1 through 6),
2) classifying the statements on the most significant threats and opportunities expressed by the biotechnology company leaders (Chapter 3),
3) analysing the earnings potential of biotechnology related intellectual property rights (Chapter 4),
4) comparing the financial sources and realised business activity of the biotechnology businesses by region within the country (Chapter 5),
5) combining the results of the above discourses and applying them to the identified industrial clusters (Chapter 6).

Based on the analytical results and the international trade framework, this book provides important policy implications for both governmental bodies involved in innovation policy and start-up companies on their way to global markets.

Helsinki, 20 February, 2006

Sixten Korkman
ETLA, Managing Director

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We would like to thank those 89 anonymous leaders of the Finnish biotechnology companies who participated in the ETLA biotechnology survey at the end of 2004 and expressed their opinions on the prospects of the Finnish biotechnology industry. We also appreciate Mikko Paakkola's efforts in interviewing representatives of biotechnology companies and coding the data. The discussion with students in a class of BioBusiness in the Institute of Medical Technology is appreciated. We also express our gratitude to those who sent their comments by e-mail and who are referred to here as anonymous. We also appreciate earlier fruitful discussions with Riikka Heikin-

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25th January 2006, in Evanston and Helsinki

Raine Hermans and Martti Kulvik

Summary

This book analyses the features of the Finnish biotechnology industry from three complementary perspectives as a basis for a strategic sustainable biotechnology development framework:

1) How do the company leaders see the future of the industry?
2) How do the companies value their intellectual property rights?
3) How does the regional resource allocation reflect the prosperity of the industry?

The strategic framework stresses orientation towards customer value as opposed to a strongly technological focus; the development of biotechnologies should not contain any intrinsic value *per se*. The commercial value of biotechnology could be benchmarked against the value of alternative technologies, and consequently, biotechnology could become part of the technology options for companies active in established and conventional industries.

The government might have an important role in preparing the companies for the harsh realities of the global market place and strengthening the links with the existing industrial pillars. However, the framework suggests the public support should be only temporary in each field of application and for any single company. Furthermore, the public sector should strengthen those ventures that share the government's long-term goals of sustainable development, or those that utilise a regionally sufficient critical mass of skilled and specialised production factors.

The tools and forecasting methods applied and developed in this book could form a justified foundation for further discussion and measures. These tools could also be used in other high technology sectors at an infant commercialisation stage.

Below we present six central policy implications open to discussion:

1. Biotechnology in parallel with other technologies in public sector technology programmes. In order to ensure that technologically advanced projects reach their economic potential, the public sector should organise their technology programmes with the primary aim of developing specific industrial application areas or processes instead of a sole commitment to a certain technology field. The central issue is to guide the technology development projects to meet the needs of the market place. Accordingly, the technology programme on energy applications, for example, might subsidise research and development also in potential technological fields of conventional physical and more modern biological technology, not solely in biotechnol-

ogies. The biotechnology development should be mirrored and compared against presently dominant technologies in the production and utilisation of the specific application. If, and only if, a new technology offers clear advantages to the existing technology, the new technology should be strongly [but temporarily] supported.

2. Bioinformatics as a basis for the distinctive application areas. Utilising the Finnish population and patient databases would necessitate a strong development of the Finnish bioinformatics research and industrial activities. Furthermore, there are many application areas within plant and industrial biotechnologies. The accumulated competencies in the Finnish information and communication technology (ICT) sector provide a strong resource that could be exploited in the field of biotechnology. The creation of commercial applications in bioinformatics might bring together highly competent business experts of the Finnish ICT sector, venture capitalists and the biotechnology industry.

3. Public sector promoting R&D programmes: emphasising sustainable development. R&D projects of the biotechnology companies are aimed at increasing the owners' wealth. Sustainable development, which is focused on long-term perspectives, does not necessarily provide any incentives for the leaders of a company. The public sector could be a sole actor steering the company's R&D activities to such application areas, which are aligned with the strategic aims of the public sector related to sustainable development. Society could define how much it would be willing to pay for the promotion of sustainable development, and the biotechnology companies could assess the opportunity costs of the societal goals with the terms of financing from the private sector.

4. Public sector subsidising start-up companies: the customer approach. The public sector can set economically meaningful policy goals, which support sustainable development. As an example, the public sector can pursue restrictions on the increase of health care costs. Accordingly, a public sector financier should demand the same goals from the project that it subsidises; the public sector acts as a customer. Such behaviour would also steer the subsidised start-up company to consider the customer benefits. This requires the company to place special emphasis on pricing the product, and to communicate the cost-benefit ratio in measurable terms. The latter creates a basis for a solid valuation of the company. Thus, the public sector's role as a customer advances the accumulation of business attitude and competencies within the company.

5. Public sector financing biotechnology companies: the venture capital approach. The financing body of the public sector can provide

external market-based financing for the companies at a more matured stage. In order to avoid serious market disturbances, the finance terms should be comparable to those of a private venture capitalist. Conventional milestones are set according to the strategy of the biotechnology company. If the R&D activities and the commercialisation do not proceed according to set milestones, the governmental venture capitalist performs a sanction; the project can be cancelled, the related IPRs can be realised or the ownership of the company can be transferred to another party. The failure of a publicly funded project should, however, produce some spill-over effects to other commercialising organisations in society, as opposed to privately funded projects. In all cases it is imperative that both parties have a clear incentive to act as transparently as possible, with clearly defined upside and downside risks.

6. The creation of globally competitive clusters. The biotechnology sector would benefit from the formation of clusters built on domestically abundant but globally relatively scarce resources that are regionally identified as critical masses. These clusters should be based on:

a. Unique factors of production
b. A domestic market laboratory
c. An internationally competitive supporting industry
d. A clearly communicated and well exercised sequential strategy.

The public sector can, for a limited period, boost such parts of an industrial cluster that are identified as being critical elements for long-term economic growth. We identified four clusters. This is however not an exhaustive list, and the identified clusters are, for example, pending on legislation and preferences of the public sector.

The development of biotechnologies should not contain any intrinsic value *per se*. The commercial value of the biotechnology could be benchmarked with the value of alternative technologies; and consequently, biotechnology could become part of the technology options for companies active in established and conventional industries.

The efforts in Finland have created a strong domestic biotechnology industry base. In the following step the key issue is to capture highest possible value from the efforts expended. We hope that the tools and forecasting methods applied and developed in this book and the appended related articles, could build a justified pathway for further discussion and measures.

The developed tools could favourably be used in other high technology sectors at an infant commercialisation stage as well. To that end, the valuable experience gained from the creation of the Finnish biotechnol-

ogy industry could be utilised even more pro-actively when considering prospective technological leaps.

Nanotechnology has been described as the next paradigm shift in technology. Being both highly technological in nature as well as generic by definition, it bears clear resemblance with the expectations put on biotechnology 1-2 decades earlier. Consequently, it could be fruitful to extend the presented methods and analyses to the context of nanotechnologies. This should be done in the near future, while the sector is still in its infant stage, at present an estimated 15 years behind biotechnologies in terms of commercial applications. The presented strategic framework, based on international trade literature could provide a solid basis for innovation policy and business activity in the small and open Finnish economy – before dedicating to major investments.

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CHAPTER 1

Sustainable Technology Development and International Trade

Hermans, Raine – Kulvik, Martti

1 Sustainable Technology Development and International Trade

In 2002 we initiated economic research on the Finnish biotechnology sector within a project called "*The biotechnology industry as part of the Finnish National Innovation System*" and financed by Tekes, the National Technology Agency of Finland. In the course of our research, the need for a strategic initiative for biotechnology became obvious. Our interviews with 89 Finnish biotechnology leaders conducted at the end of 2004 further corroborated our inference.

This book concludes our findings from the research conducted on the Finnish biotechnology industry. In addition, it identifies global megatrends that threaten the future well-being of Finland. Our aim has been to try to take advantage of these megatrends and analyze the opportunities that they might provide within the context of sustainable biotechnology development[1], with the ultimate goal of creating a strategic framework that could be applied to mould the future of the Finnish biotechnology industry.

In this chapter we present four concepts that form the basis for topical economic research within international trade theory, and begin to construct a dynamic framework based on them. Chapter 2 describes the present state of the Finnish biotechnology industry. The analysis is based on three Etla surveys carried out in 2002, 2003 and 2004. The 2003 survey contains only qualitative interviews, whereas the other surveys delivered both quantitative and qualitative data. Eight journal publications are presented that build on the results from the first two surveys. Data from the Etla survey of 2004 has not been published previously and is therefore described in more detail here.

Chapters 3 to 5 present results from our most recent research, as well as implications thereof. In the last chapter we finalise our dynamic framework and apply it to identify potential application areas where the Finnish biotechnology sector could have a significant impact. After depicting a strategy that extends to the future we conclude by introducing six policy implications to be, we hope, discussed further within a larger context.

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[1] In our paper, we use the term sustainable development with a specific focus on Finnish implications.

1.1 Finland and the Global Megatrends

Finland has been rated one of the top countries in international competitiveness (IMD 2004). However, this competitive nation does not attract investments, is not the leading country in terms of living standards and is unable to eliminate its high unemployment rates; this has been described as the *Finnish paradox* (Suomi globaalissa taloudessa: Suomen paradoksi 2005). Furthermore, Finland is strongly affected by several global megatrends:

Firstly, the global population demographics are becoming more extreme and more divided. Developing countries in Africa show high birth rates and low life expectancies, a development severely aggravated by HIV, whereas the population in Western Europe is diminishing and aging leading to a potentially severe deficit in work force and threatening production. Besides strains on retirement systems, the ageing of the population in Europe will threaten the supply of public healthcare for everyone. Healthcare-related "red" biotechnology might play an important role in the restriction of increases in healthcare costs by providing new cost-efficient healthcare applications. Additionally, some applications for functional food might proactively bring forth some positive health outcomes and prevent the generation of costs related to particular diseases in the first place. In many cases, it would be more cost-efficient to create preventive mechanisms than treat those illnesses.

Secondly, the extensive use of fossil fuels is identified as a major threat to the global bio-system. We are faced with the fact that several of the global environmental problems will continue to worsen during the next 15 years, irrespective of even the strongest possible countermeasures. Pollution, erosion and global warming are among the most evident changes to be encountered.

Thirdly, as oil reserves outside the Middle East are becoming depleted, the rising prices together with geographically skewed production will probably strain the existing economic balance. However, applications of "green" plant biotechnology and "white" industrial biotechnology could provide some solutions for producing, for example, bio-fuels instead of polluting fossil-fuels, as well as growing specific crops that take advantage of the Arctic dimension of the Finnish environment.

Fourthly, globalisation has entered its third stage, where R&D functions are being relocated to developing countries such as China and India. With the global outsourcing of research and development, also knowledge flows away from the original location of the innovation. A central question for Finnish biotechnology is: are we able to offer sufficient incentives for the

global players to anchor innovative R&D to Finland, and thereby catch the upside potential in a globalizing and service-oriented world?

Fifth, it is claimed that we are yet in the early phase of creating knowledge-intensive, high-technology solutions to global phenomena. Technology-orientation and digitalisation are assumed to expand to all areas of human life, probably through integration with life-science based innovations. *Ubiquitous computing* and *hybrid society* are expressions used to describe our future. By definition, biotechnology is one of the central concepts in a technology-oriented world.

1.2 Analytical Background of the Strategic Initiatives

Healthcare technology has been regarded as the main application area of biotechnology, but the applications of plant and process biotechnology are gaining in importance. Irrespective of the application area, the technological interests and the market potential are global. An interesting example is in food production, where innovations such as Golden rice and Bt (*bacillus thuringiensis*) wheat are discussed as a step towards balancing the global inequality of food production. Even though we focus on the potential synergy between innovation clusters in a domestic context, the markets – and the competition – are global.

The key question for the success of the Finnish biotechnology industry is to be able to take advantage of our domestic strengths, acknowledge our limited resources, and yet realise the global view of biotechnology. Our goal has been to connect our findings from the Finnish Biotechnology sector to the major trends recognised in the literature concerning international trade theory. Consequently, the following concepts form the basis of our dynamic strategy framework:

1.2.1 Comparative Advantage

Ricardo's concept of comparative advantage has formed the foundation of trade analysis and has served as a basis for further modeling tradition. For instance, the Heckscher-Ohlin-Samuelson approach links the regional factor proportions and their productivity to the comparative advantage of regions (Flam and Flanders 1991, Samuelson 1948). There has been an extensive number of theoretical contributions and empirical investigations both to the Ricardian and the Heckscher-Ohlin-Samuelson modeling tradition up to the present day. According to the trade literature, all trading regions will gain if each region is specialised in production at a lower opportunity cost than

other regions. Particularly when trade barriers get lower, according to the Heckscher-Ohlin model, a region benefits if it increases the production of goods produced from the regionally relatively abundant factors.

A small open economy has limited and scarce resources. Therefore, it is not economically reasonable to produce all the products for domestic markets itself. In order to apply a comparative advantage, it is necessary that economies specialise in some specific application areas or areas utilising a specific combination of relatively abundant factors of production.

> *There will be economic overall gains within a free trade area if an industry utilises a resource combination that is domestically relatively abundant.*

1.2.2 Market Structure and Spatial Agglomeration

Krugman and Venables have emphasised the new economic geography approach (Krugman 1991, Krugman and Venables 1995, Venables 1996). They analysed how the market structure is related to the location of economic activities. The modeling of the market structure was based on the concept of monopolistic competition as presented by Dixit and Stiglitz (1977) and originating with Chamberlin (1933). The basic idea of the original analysis is to show how higher sunk costs in industrial production, for example, higher M&A or R&D costs, imply more differentiated products for consumers. In one extreme, there would be only a few producers with greatly differentiated products. In the other, however, there would be an infinite number of low sunk-cost producers in case the consumer prefers a very large variety of less differentiated products.

Krugman extends the model of monopolistic competition to a spatial context (Krugman 1991). In the geographic centre-periphery model there are three market features affecting the spatial structures:

1. Higher increasing returns to scale (IRS) in a manufacturing sector imply higher sunk costs in the production processes. This, in turn, tends to lead to a strengthening of the geographic centre-periphery structure.

2. The higher the sector's usage of available production factors, the more clearly a centre-periphery structure gains strength. This effect implies that firms gain an advantage of the local concentration of labour [or other factors] and labour's job seeking costs become lower due to the proximity of high number of companies.

3. Lower trade barriers or lower trade costs imply a tendency towards the spatial agglomeration of the IRS sector. The firms can also subcontract with each other locally, with relatively low transport costs (Krugman and Venables 1995, Venables 1996).

Peripheral regions (such as Finland) can attract companies as a basis for value-adding activities if there is a critical mass of location-specific but globally scarce resources available in the periphery.

1.2.3 The Infant Industry Argument

Hamilton's and List's original contributions argued for the public support of the infant industry to achieve a leading position over other countries (widely discussed example on its empirical test: Krueger and Tuncer 1982). The infant industry argument (IIA) is based on the temporary need for protection (or support) of an infant industry if the industry is unable to grow in the international context of free trade and foreign rivals. The initial excessive costs of the industry support are assumed to be compensated by the later stages' excessive profits and economic growth, not captured without the short-term governmental support. However, IIA has been misleadingly utilised as an argument for exceedingly long-term protection, against the original view.

There are some basic arguments that provide a rationale for the supporting activities, such as cumulative learning within the infant industry through the creation of positive externalities. The potential externalities over time include, for example, availability of technically competent labour, technological spillovers, and diminishing transport costs due to the creation of a local cluster. If these externalities could be created only through governmental promotion, and if the long-term GDP effects exceeded the initial short-term costs of the promotion, it would be reasonable to provide a temporary support scheme for an infant industry. The infant industry argument diverges thus from the static trade restriction schemes which protect domestic industry through permanent import tariffs or quotas or by other supporting schemes.

A short-term injection of governmental promotion for the strengthening of some emerging critical resources within an infant industry aims at providing positive externalities and an economic upside in the long term.

1.2.4 Cluster Dynamics

Porter (1990) concludes the discussion on spatial competitiveness with a discourse on industries' ability to create radical and incremental innovations. In Porter's diamond model, innovation intensity depends on the interaction among four attributes:

1. Factor conditions
2. Demand conditions
3. Related and supporting industries, and
4. Market structure.

Skilled labour and a well-developed infrastructure are critical factors of production and innovations; if there are demanding and sophisticated customers in the domestic marketplace, the companies are forced to be innovative. An internationally competitive supporting industry is a key to the availability of cost-effective inputs. Competitive domestic markets with innovative rivals intensify the innovation processes, as well as the construction of a first-mover strategy.

The interaction of highly specialised resources, sophisticated domestic customers, internationally competitive supporting industries and hard domestic competition creates an innovative and competitive industrial cluster.

1.3 Combining the Theories: the Way to Proceed

The four central concepts presented above are traditionally seen as substitutes for each other. However, our intention has been to find new insights into a strategy by seeking ways to fuse even seemingly contradictory frameworks or sectors; we believe that added value can be found in the interfaces. As the biotechnology industry extends its sales to the global markets, it seems logical to focus on the combination of central frameworks derived from the literature of international trade.

We firstly analysed the components of the frameworks with special focus on potential implications for the biotechnology industry. The combination of the implications can be stated as follows:

Create a comparatively abundant, location-specific and globally scarce interactive combination of

1. *Competent factors of production and infrastructure,*
2. *First-class and sophisticated domestic customers*
3. *Internationally competitive supporting industries,*
4. *A competitive domestic environment*

by strengthening temporarily those parts of the infant industrial cluster which are critical for the long-term growth and success.

In the next step we superimposed the chosen frameworks to a logical unity. By introducing a dynamic aspect, the frameworks could then be linked seamlessly to each other as presented in this chapter. The following chapters describe in more detail how our latest research was integrated to form the final dynamic framework describing present and future aspects of the Finnish biotechnology sector:

Chapter 2 summarizes Etla's published research on the Finnish biotechnology industry. It also presents our data from the second ETLA survey (ETLA 2004) with special emphasis on the concept of intellectual capital. Throughout this book data is presented using the concept of Intellectual Capital (IC) as it offers a tool for both assessment and management of the economic potential inherent in a knowledge intensive sector. For a further discussion see appendices IV (Measuring intellectual capital and sources of equity financing), V (Funding Intellectual-Capital-abundant technology development) and VI (Value creation potential of Intellectual Capital in biotechnology).

The value creation potential of the biotechnology sector lies in skilful knowledge management[2]. The challenging task of the biotechnology business leaders is to tie together the key success factors into an integrated strategy (Figure 3.1). **Chapter 3** describes the views of 89 biotechnology business leaders on their own industry. It also reflects the internal potential of the Finnish biotechnology sector for this critical and potentially prosperous integration process.

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[2] Appendix 4 (Measuring intellectual capital and sources of equity financing) and Appendix 6 (Value Creation Potential of Intellectual Capital in Biotechnology) of this book describe the process in more detail, based on data derived from our research on the Finnish biotechnology companies.

Patents form the central pathway for creating value from the intangible assets in a knowledge-intensive business. The potential of patents to create earnings can be assessed based on their technological significance and, thus, economic value. **Chapter 4** describes this process as part of the value creation strategy of the Finnish biotechnology sector (Figure 4.1).

Chapter 5 assimilates the concepts of Comparative Advantage and Geographical Economics with the findings of regional specialisation and industrial clustering of the Finnish biotechnology sector. This is visualised in the lower part of our dynamic framework (Figure 5.1), with supporting industries as a key element in the process. Appendix 2 (Price-cost Margin in the Pharmaceutical Industry) sheds light on the background of the supporting industry of health care applications.

Our dynamic model depicts the value creation life cycle in the biotechnology industry, from basic innovation to eventual global markets. After unique factors of production have been identified, the R&D effort in respective sectors is promoted by early-stage public sector support. A deeper insight into the issue is included in **Chapter 6**, where the role of the public sector is discussed.

The following figure (Figure 1.1) presents how we combine the results and policy implications obtained from Chapters 3-5 and relate them to the context of a strategic framework derived from Chapter 6.

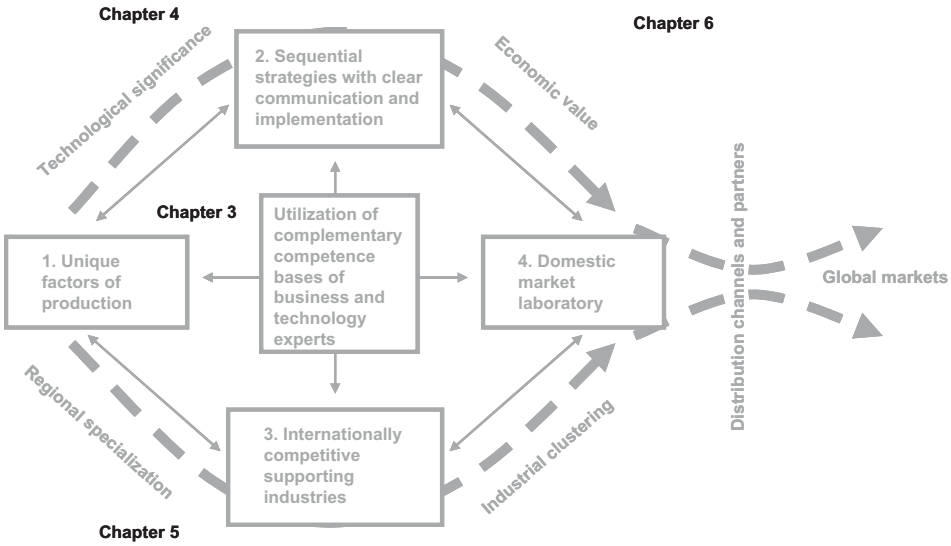

Figure 1.1 The combination of our distinctive research paths in the strategic context of international trade analysis

The framework sets our findings in the context of the Finnish innovation system and global markets in two perspectives.

First, technologically significant and economically valuable intellectual property rights provide a base for the construction of a business strategy in order to exploit the sophisticated domestic markets in a pathway to the global markets.

Second, regional specialisation of commercialisation activities can provide a critical mass of competencies serving as a base for specific industrial clusters.

If the infant biotechnology industry could provide complementary competencies and earning prospects in the future for more matured industries, these could finance and facilitate in the development of the infant biotechnology industry.

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CHAPTER 2

The Biotechnology Industry in Finland

Hermans, Raine – Kulvik, Martti
– Tahvanainen, Antti-Jussi

2 The Biotechnology Industry in Finland

The biotechnology sector is expected to initiate a new phase of technological development that will have a pronounced impact on economic growth. ETLA has been involved in the research of managerial economics of biotechnology since the beginning of 2002. Several overviews and analyses of the Finnish biotechnology industry have been made, with most of the results of these studies presented and published by Hermans, Kulvik and Ylä-Anttila (2005) (Appendix I) and Hermans (2004). ETLA carried out two surveys of biotechnology companies, the first in spring 2002 and the second in autumn 2004. This chapter describes the data of the second survey.

2.1 Background

The number of biotechnology companies grew sharply until the beginning of the millennium. At the end of 2003, there were about 120 biotechnology companies in Finland, with no significant change from 2001. Despite stagnation in growth, the Finnish companies constitute almost 7 % of the total biotechnology companies in the European Union (EU). This is a considerable amount if we compare it to Finland's population of 5 million, about 1.3 % of the EU population in 2003. Finland can be considered a biotechnology intensive country. However, Finnish companies are limited in their size and ability to exploit their market potential: about 110 of the Finnish companies are small or medium-sized.

Most of the Finnish biotechnology business activities are related to health care applications. Almost 60% of the small and medium-sized biotechnology companies are active in the pharmaceutical industry or research. The pharmaceutical markets hold high growth expectations due to the development of medical research and the ageing of the population.

However, the risks related to drug development are also high due to a particularly risky research and development (R&D) process, as well as the complex nature of global marketing. This leads giant pharmaceutical companies to control the risk through external collaboration in R&D activities. Thus, many giant pharmaceutical companies have outsourced part of their biotechnology-based R&D activities to small research-intensive biotechnology companies.

The second ETLA survey of the Finnish biotechnology sector focuses primarily on these small- and medium-sized biotechnology enterprises

(SMEs)[1]. This narrower focus is justified as the inclusion of the handful of giants active in Finland would distort and eliminate effects that the numeral majority of biotechnology companies have on the analyses[2]. Furthermore, one could assume that larger and more mature companies resemble those in other sectors in terms of company characteristics relatively more than small and medium-sized companies due to the more consolidated state of business. Thus, the inclusion of large-sized companies might have diluted and disguised findings stemming from distinctive characteristics that the biotechnological component accords to the business.

This chapter serves as a depiction of the Finnish biotechnology industry at the end of 2003 and is organised as follows: Following on the introduction, Section 2 gives an overview of the conclusions made from the preceding ETLA 2002 survey published in or submitted to international scientific journals. Section 3 presents some descriptive statistics on the ETLA 2004 survey through three complementary approaches. The first approach deals with intellectual capital, the second with financial sources, and the third with regional context. Finally, Section 4 concludes and suggests further research.

2.2 Overview of the Previous ETLA 2002 Survey

The first ETLA survey on the Finnish biotechnology industry was performed in March-May 2002 by ETLA and Etlatieto Ltd and first reported by Hermans and Luukkonen (2002). The survey was carried out through telephone interviews. There were 116 companies in the population, which was obtained from the Finnish Bioindustries Association. Eighty-four companies replied, which translates into a response rate of 72 %. Despite the high response rate, the sample was partially skewed towards matured companies. There were proportionally fewer infant companies, founded 1997-2001, in the sample than companies in other age groups.

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[1] SMEs in this paper are defined according to official definitions of the EU excluding companies with over 250 employees and match additionally at least one of the following criteria: (i) Annual turnover > 50 mill. EUR, (ii) balance sheet total > 43 mill. EUR. Departing from the official EU definition, we include those daughter companies owned by large parent companies in our SME sample, if they match the above definition in every other aspect.

[2] Orion Pharma alone, for example, has publicly disclosed it has over 2,400 employees in Finland compared to the total employment of all Finnish biotechnology SMEs of about 2,500.

Several articles have been published in international scientific journals based on the preceding ETLA survey; the articles are appended to this book in their original form. In the following we will summarize the articles that deal with themes in the field of managerial economics of biotechnology. Each contains policy implications for both the industry and the public sector.

Hermans, Kulvik and Ylä-Anttila (2005) (Appendix I) suggest that, in order to fulfil the expectations of the success of the Finnish biotechnology industry, it is necessary to create a critical mass of factors of production and comparative advantage by building collaboration and financing networks between the biotechnology industry and more traditional industries, such as the forest industry, the electronics industry and the pharmaceutical industry. Since most of the current Finnish biotechnology companies are related to health care activities, Appendix I argues that the Finnish biotechnology industry could offer solutions to the cost crisis in health care while spurring the development of an internationally competitive industrial cluster at the same time.

Linnosmaa, Hermans and Hallinen (2004) (Appendix II) estimate the price-cost margin in the Finnish pharmaceutical industry. The results show that the estimated price-cost margin is in the same range as the estimates obtained in US markets. Although the segmentation of markets between patent-protected and generic products may lead to the same average overall price-cost margins, there might, however, be some major differences between the market structures of these two countries.

Process patenting was acknowledged in Finland meaning that Finnish companies have been able to produce drugs already patented abroad. However, after the harmonisation of Finnish patenting legislation with the EU legislation, the Finnish companies met the same challenges as their foreign counterparts, putting pressure on their price-cost margins. Furthermore, due to the considerable costs and risks associated with drug development, the large pharmaceutical manufacturers have begun to outsource the initial stages of their research and development activities to small biotechnology companies.

Tahvanainen (2004) (Appendix III) describes the characteristics of small Finnish biotechnology companies that have their origin in academic research conducted in universities or other comparable research institutions. The results show that the academic spin-offs are technology-focused while they lack a clear market-oriented focus. This is apparent in that there is often no long-term business plan, co-operation activities are relatively poor and companies rely heavily on lead-time to protect their innovations. Despite a large number of infant drug development companies, Finland does

not have an industrial history of being a first mover in the development of pharmaceuticals. In many European countries and in the US, managers have been recruited from, for example, the traditional pharmaceutical industry, and venture capitalists with specific biotechnology business expertise have also brought business skills into their portfolio companies. Lacking such a history, there is no large pool of skilled individuals with a relevant business background in Finland. At present, Finland's main early stage investors are unable to exit from their present portfolio companies, thus new equity capital is almost unavailable for new start-ups.

Hermans and Kulvik (2004) (Appendix IV) compare intellectual capital profiles of the small Finnish bio-pharmaceutical companies with their distinctive ownership profiles. Other companies possess equity in bio-pharmaceutical companies with two different profiles of intellectual capital. This probably reflects two different subgroups of companies, corresponding to different strategic functions designated to the company by the owner firm (*e.g.* only research activities in a specific phase, or a fully integrated company). Private venture capital companies seem to prefer a well-balanced combination of intellectual capital, even more than other owner groups. This indicates their ability to either monitor the most promising companies or effectively guide the knowledge management of the company they have invested in. Individual owners, state venture capital institutions and other investors showed among themselves a rather similar pattern of investment preferences. The role of individual owners and state venture capital institutions is emphasised in the early stages of a bio-pharmaceutical company's life cycle. These investor groups have directed funds to companies, whose intellectual capital profiles are not fully balanced, thus reflecting a deficient value creation potential.

Tahvanainen and Hermans (2005) (Appendix V) deepens the analysis on how an intellectual capital profile of a company affects its capital structure. While companies with well-balanced intellectual capital (IC) profiles have relatively high retained earnings and debt ratios, companies with only structural capital (e.g. a solid patent portfolio) display relatively high capital loan ratios. Companies whose IC bases consist of human capital (e.g. business and technology competencies), and relational capital (e.g. collaboration networks) only, show relatively high external equity ratios. In a static framework one can argue that the findings are in line with the financial pecking order hypothesis of Myers (1984), implying that, despite existing knowledge management metrics deliberately created for the measurement of IC, an information asymmetry concerning the IC of companies still persists between sample companies and financial markets.

As a policy implication Appendix V suggest that IC metrics should be applied in investment decisions. IC metrics could be used to position an individual firm in the context of the entire industry. It seems that IC metrics could stand as a basis for the evaluation of the most promising investment decisions and for a strategically meaningful development of the companies after an investment decision.

The present value of a company is based on the expectations of its future returns. However, in the biotechnology industry the historical accounting data does not typically enable us to form expectations based on previous revenue and profitability figures because most of the companies virtually lack revenue or do not make a profit. When investing, external investors should have indicators at hand that help them project future earnings in light of the company's current situation. Without such measures, the earning expectations with respect to the potential investment target may be distorted. **Hermans and Kauranen (2005)** (Appendix VI) quantify the value of a company's intangible assets and model the intellectual capital and value creation of companies from the perspective of knowledge management. Technically, the model's ability to explain 70% of the variance of the anticipated future sales controls for the risk of randomness of these anticipations disclosed by the biotechnology companies. This means that a large portion of the companies' growth expectations is based on the value stemming from intangible assets. The approach offers a means of valuing companies based on the companies' IC metrics. Using knowledge management assessment, an individual firm can be positioned in the context of the entire industry, which can further reveal critical qualities hidden from conventional approaches.

Luukkonen (2005) (Appendix VII) describes the organisational forms of the Finnish biotechnology SMEs. The forms of organising networking activity are classified by distinctive application areas. For instance, drug development companies, with strict regulatory requirements, often organise their activity as a network company and rely on a strong property rights regime and out-license their IPRs both in mass and niche markets. This might reflect the fact that there are not many fully-integrated pharmaceutical companies within the sample of Finnish SMEs. However, some other application areas, for example industrial enzymes and animal feed, organise their business activity as a vertically integrated company. According to these findings, Luukkonen (2005) relates the reasons for the variability of the organisational forms within the distinctive application areas to their regulatory environment, technological risks and sunk costs of the product development. Thus, the market structure and environment influence the financing required by companies.

While Hermans and Kauranen (2005) (Appendix VI) control for randomness of the anticipated future sales at the company level, **Hermans and Kulvik (2005)** (Appendix VIII) control for a systematic error at the industry level; that is, a tendency of the entire biotechnology sector to overestimate the level of anticipated future sales over the period of the survey. To this end, Hermans's and Kulvik's (2005) study compiles an economic growth forecast where the probability distribution is formed from the companies' sales growth forecast, their current sales revenues and the bankruptcy risk. The modelling technique is based on the sectoral input-output method utilising the purchase and sales volumes announced by companies in the respective sectors, followed by a Monte Carlo Simulation that produces the output predictions. Finally the biotechnology sector is compared to the existing three pillars of the Finnish economy: if the long-term growth rate of production of the biotechnology sector is sustained at the same level as in the forecast period 2001-2006, it should take 15-30 years to reach the same production level as the electronics or pulp and paper industries have in Finland today.

The rest of the present chapter is dedicated to the presentation of findings obtained from the ETLA survey 2004. Unlike the articles summarized above, these findings have not been available to the public through international journal publications thus far, and will therefore be dealt with in detail here. To provide the presentation with a clear structure to follow, the observed issues are categorized according to the Intellectual Capital (IC) framework discussed more in-depth in Chapter 3. Many of the above studies and those to come lean on the IC framework, as it explicitly emphasizes the role and importance of knowledge and knowledge creation in the value creation process of companies. It is a notion that is inevitable in the research of profoundly knowledge-intensive industries such as biotechnology.

2.3 Descriptive Statistics of the ETLA Survey of 2004

The empirical evidence of the present ETLA survey is based on new data collected via a telephone questionnaire in the late fall of 2004. It is supplemented by financial statement data from The National Board of Patents and Registration (NBPR). All data describing the current state of the companies represent 2003 figures. In some individual cases financial statement data from NBPR originates from periods before 2003 as 2003 statements were not submitted to NBPR by all the sample companies. However, no data from NBPR is used from periods before 2001.

The survey covers the majority of companies operating in the Finnish biotechnology sector. As the survey focuses on dedicated biotechnology companies, cluster firms specialising solely in distribution, import, consulting and other support functions are excluded from the survey. Our sample includes 87 out of 123 active biotechnology companies in autumn 2004, and 79 out of these 87 are small or medium-sized. The total amount of biotechnology SMEs in Finland is 111. These numbers translate into a response rate of 71% with respect to both total- and SME populations. Reasons for not obtaining data covering the complete population include no response, incoherent data and the non-existence of an exhaustive list of companies active in the sector at the time of survey implementation[3].

Although companies of all ages are represented by the sample fairly evenly, very young companies, on the one hand, and very old ones on the other are slightly better represented than adolescent or middle aged ones. Concerning NBPR data on financial statements it should be pointed out that the sample is almost identical to the total population as financial statements could be retrieved from 117 companies (95%). Analyses based on this data are therefore highly representative.

The companies in the final sample are independent businesses, partnerships or subsidiaries of bigger corporations. In the latter two cases the businesses had to be independently responsible business units in order to be included in the sample. If the criteria were not fulfilled, the data was collected from the parent company.

The survey covers a variety of topics, ranging from the basic characteristics of companies to the conduct of R&D to sources of financing and sales, as well as collaboration patterns and purchasing. In this respect, the survey updates the data collected in the first ETLA survey of 2001.

However, the current survey is more profound in that it features the aforementioned aspects in more depth. New insights include geographical and inter-institutional R&D-collaboration patterns, mapping of the academic science base on which the companies build their own R&D, detailed, comprehensive and reliable financial statements, and, probably most importantly, product-level data that incorporates R&D- and sales figures, forecasts thereof, collaboration patterns, product-specific science-base mapping and academic origin of the innovations. Through these new features the

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[3] In autumn 2004 the Finnish Bioindustries Association Index was updated, during which the definite number of companies active in the Finnish Biotechnology sector could not be determined. Our sample of 123 companies is based on the Index as of September 2004, but includes additional companies tracked down from a variety of sources.

data allows a more thorough and detailed analysis of the sector than could have been carried out before.

2.3.1 Intellectual Capital in Small Biotechnology Businesses

As mentioned earlier, the presentation of survey findings will be structured according to the intellectual capital (IC) framework. We base the measurement of IC in the sample companies on the principles presented by Edvinsson and Malone (1997). The names for the three components of IC, **human**, **structural** and **relational capital**, have been modified to match the definitions proposed by the MERITUM project (2002) (see also Sveiby 1997 and Edvinsson and Malone 1997). Edvinsson and Malone (1997) talk about 'customer capital' instead of 'relational capital', thereby disregarding relationships to all other stakeholders like suppliers, competitors and academia. However, the latter are critical for advancing research towards the market place, as successful R&D activities often are conducted within networks of co-operation (see e.g. Nilsson 2001).

According to the value platform model (Edvinsson and Malone 1997), value is created in a company when all three components of IC interact. While **human capital** encompasses the knowledge, experiences, skills and competencies of the personnel, **structural capital** comprises physical and conceptual structures present in the company that facilitate the support, enhancement, protection, intra-firm distribution and documentation of human capital residing in the company. **Relational capital** can be understood as a network of virtual and physical relationships and connections among the critical stakeholders of a company. Through this network the company is able to leverage intra-organisational achievements, be it products, intellectual property rights, services, results of research, communication or people to the periphery of the company. According to the model, all three components are critical success factors in the sense that in the absence of any single component only modest value can be created.

Human capital

As knowledge in its natural, uncodified, and tacit form resides within individuals, we utilise the total number of personnel to capture and quantify the total mass of knowledge inherent in the companies. As the biotechnology industry is knowledge-intensive in character and depends on human capital for innovation, we assume that a critical mass of complementary and cohesive human capital is essential for exceptionally high performance, or taken to the extremes, for survival.

Table 2.1 Descriptive statistics of human capital related variables of the Finnish biotechnology SMEs

	N	Sum	Mean	Median	Std. Deviation
Personnel	100	2,450	24.5	10	41.34
Personnel holding doctoral degree	75	273	3.6	2	5.49
CEO's business experience (years)	76	919	12.1	10	8.74
Full-time marketing expertise (no=0; yes=1)	78	52	0.67	1	0.47
Full-time production process expertise (no=0; yes=1)	79	40	0.51	1	0.50

A typical Finnish small biotechnology company has 10 employees of whom one in five holds a doctoral degree (Table 2.1). The company's chief executive officer has 10 years business experience and some of the company's personnel have marketing expertise.

Structural capital

Structural capital includes the way of organising the company's activities and the intellectual property rights of the company. The structural capital of a company includes activities, schemes, policies and programmes, as well as systems, regulations, guides, rights and facilities that support, enhance, protect, distribute and document the human capital in that company. In more concrete terms this includes the organisation of activities like R&D, the protection of R&D investments with immaterial property rights, company policies on diverse aspects like secrecy and competing activities, information systems and guidelines concerning the standards of conduct in the laboratory, as well as bonus and educational programmes.

The typical Finnish biotechnology company was founded 7 years ago (Table 2.2). R&D expenditure is 180,000 euros annually. Due to the intensive R&D activities, its patent portfolio contains 4 patents or patent applications, of which about half are officially accepted.

Table 2.2 Descriptive statistics of structural capital related variables of the Finnish biotechnology SMEs

	N	Sum	Mean	Median	Std. Deviation
Age (years)	79	869	11	7	15.28
Number of patents and patent applications	76	640	8.41	4	14.02
Number of patents and patent applications per personnel	76	83.9	1.10	0.32	2.63
Patent applications per sum of patent applications and patents	56	28.5	0.51	0.50	0.35
R&D expenditures (euros)	81	71,076,842	877,492	180,000	1,454,796
R&D expenditures per personnel (euros)	79	4,262,708	53,958	18,143	147,793

Relational capital

Market potential and catering to customer needs are fundamental requirements for success in any business. Edvinsson and Malone (1997) and Stewart (1998) define the company's relational capital as customer capital, and Sveiby (1997) also takes into account supplier networks in relational structures. Most of the future of the market potential in small open economies results from the anticipated sales in international markets. When speaking of the early-stage biotechnology companies, a pre-requisite in the field of relational capital is research and development collaboration and investor networks as a strong science base is necessary to attract large investments. (Zucker, Darby and Armstrong 2002.)

The typical small Finnish biotechnology company collaborates with universities, research institutions and other companies (Table 2.3). It has also obtained state financing. Most of the companies in drug development and diagnostics collaborate with clinical units.

Almost half of the companies have a principal customer (≥ 33 % of the company's sales). Over one-fifth of the companies have a principal subcontractor, from whom they purchase over 33 % of their input for research and development and production activities.

Value creation of intellectual capital

Total sales of the small biotechnology industry reached 330 million euros in 2003 leaving the industry still unprofitable. Operating losses were 60 million euros during this period and net losses amounted to 70 million euros.

Table 2.3 Descriptive statistics of relational capital related variables of the Finnish biotechnology SMEs

	N	Sum	Mean	Median	Std. Deviation
R&D collaboration with own group	79	13	16.5 %	0	37.3 %
R&D collaboration with other companies	79	64	81.0 %	1	39.5 %
R&D collaboration with clinical units	78	28	35.9 %	0	48.3 %
R&D collaboration with universities	78	65	83.3 %	1	37.5 %
R&D collaboration with research institutions	78	47	60.3 %	1	49.3 %
R&D collaboration with others	78	9	11.5 %	0	32.2 %
State financing obtained	79	76	96.2 %	1	19.2 %
Sales to a principal customer over 33% of total sales	78	34	43.6 %	0	49.9 %
Purchases from a principal subcontractor over 33%	77	17	22.1 %	0	41.7 %

Revenues were highest in enzymes – one of the most traditional sectors of Finnish biotechnology – followed by drug development and food and feed (Figure 2.1). With over 150 million euros, enzymes make up almost half of all revenues of the small biotechnology industry. Bioinformatics is smallest with compound revenues of less than 3 million euros.

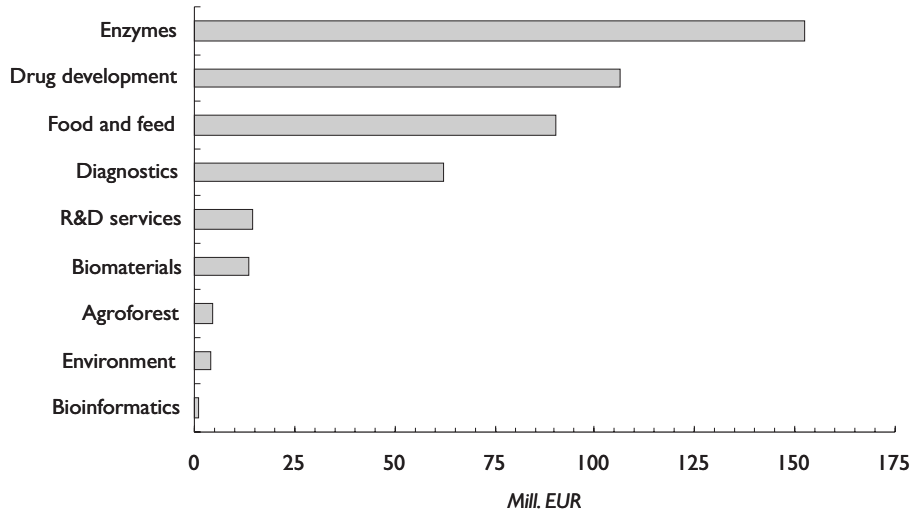

Figure 2.1 Sales of the Finnish biotechnology industry by the fields of applications in 2003

Figure 2.2 depicts average and median durations of commercialisation within distinctive biotechnology application areas. The median and average from-invention-to-sales durations seem to range within distinctive application areas between 2-6 years and 3-9 years, respectively. The higher numeric values of averages as compared to those of medians indicate that there are some inventions with relatively long realised or anticipated commercialisation durations; the duration distributions have long tails in a positive direction in all of the application areas with the exception of environmental applications. The reliability of the distributions may be questioned due to the small number of observations in some application segments (*e.g.* agriculture, bioinformatics and forestry). However, the number of these products reflects the number of companies active in that specific application segments.

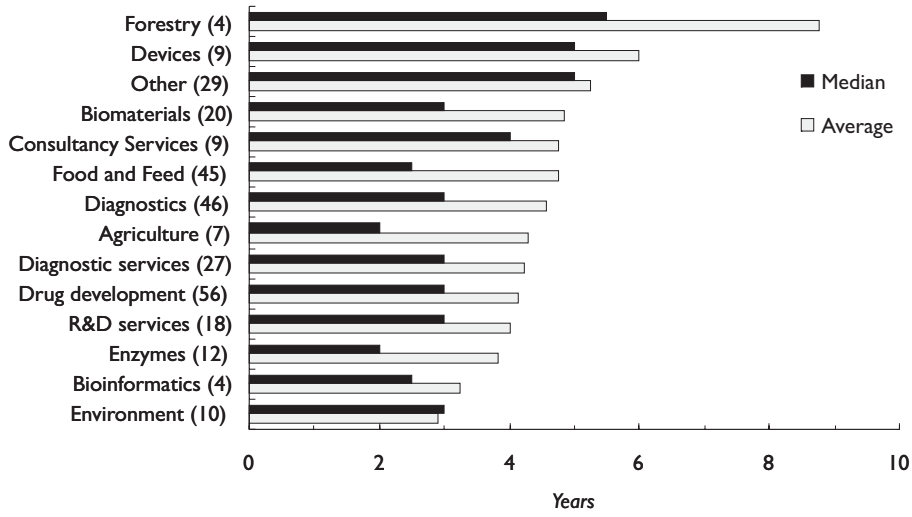

Figure 2.2 From-invention-to-sales duration in distinctive biotechnology application segments (number of product groups within the application segment in brackets)

The longest commercialisation durations seem to coincide with the applications related to the forestry and in development of devices. Slightly surprisingly, drug development projects seem to capture positive cash flows sooner than diagnostics and biomaterials. This indicates the importance of out-licensing strategies in the drug development sector in order to create the positive cash flows from sales at early development stages and survive in their highly regulated application segment. And, for instance, despite the slacker regulation environment, biomaterial developers often set their own goal to develop an innovation in-house up to its final stage, which extends the commercialisation duration. Interestingly, consultancy services take even more time

to mature than other application segments zeroing in on developing more concrete products.

2.3.2 Biotechnologies and the Fields of Applications

The terms red, white and green biotechnology are widely used to differentiate between the application areas of biotechnology. However, the terms are in part diffuse owing to the generic nature of biotechnological techniques. Especially in the field of plant technology, the application areas and the techniques have been interchanged and used without clear definition (CGIAR 1998, ACP-EU 2003).

As the terms red biotechnology, white biotechnology and green biotechnology together with their parallel expressions are very widely used, we will begin by recapitulating how the terms and classifications are used and defined. When not stated differently, we use definitions according to EuropaBio.

The broad definition of [green] biotechnology covers many of the tools and techniques common place in agriculture and food production. Interpreted in a narrow sense, which considers only new DNA techniques, molecular biology and reproductive technological applications, the definition covers a range of different technologies such as gene manipulation and gene transfer, DNA typing and cloning of plants and animals. The development of genetically modified organisms (GMOs) should be regarded as only one application of plant biotechnology, even though it has become the focus of a heated debate where morality and money have been opposed (FAO 2000, ACP-EU 2003). The aim of **green** or **plant biotechnology** is to achieve crop improvement and production of new products in plants. Currently, green biotechnology can be regarded as encompassing three major areas: plant tissue culture, plant genetic engineering and plant molecular marker assisted breeding.

Plant tissue culture allows whole plants to be produced from minute amounts of plant parts such as roots, leaves or stems or even just a single plant cell under laboratory conditions. An advantage of tissue culture is rapid production of clean plant materials.

Plant genetic engineering encompasses the selective, deliberate transfer of beneficial gene(s) from one organism to another to create new improved crops, animals or materials. Examples of genetically engineered crops include cotton, maize, sweet potato and soybeans.

Plant molecular marker assisted breeding is a technique using molecular markers to select for a particular trait of interest, such as yield. A molecular marker is a short sequence of DNA that is tightly linked to the

desirable trait (such as disease resistance) that selection for its presence ends up selecting for the desirable trait. An example is maize that is tolerant to drought and maize streak virus. (EuropaBio 2005)

The term **white biotechnology** encompasses an emerging field within modern biotechnology that serves industry. It uses living cells like moulds, yeasts or bacteria, as well as enzymes, to produce goods and services. Living cells can be used as they are, or can be improved to work as "cell factories" to produce enzymes for industry. Living cells can also be used to make antibiotics, vitamins, vaccines and proteins for medical use. Examples of applications are:

Eco-efficient enzymes which can serve as alternatives to some chemical processes to make products. Enzymes offer a biological route and often cleaner solution for industry; eco-efficient, enzymes consume less water, raw materials and energy. The environmental impact can be minimised, while offering better products at lower cost. For example, using enzymes in washing powder allows difficult stains to be removed at lower temperatures, saving energy and reducing the impact on the environment.

Biomass like starch, cellulose, vegetable oils and agricultural waste are used to produce, for example, chemicals, biodegradable plastics, pesticides, new fibres and biofuels. The processes manufacturing them use enzymes, and biomass is by definition made from renewable raw materials.

An example is ethanol, a renewable fuel made out of biomass. It has the potential to replace fossil fuels, which would have a neutral impact on greenhouse gas emissions, and could help reduce global warming. (EuropaBio 2005, Söderlund 2005)

Health care biotechnology is increasingly playing a role in conventional drug discovery. Additionally, there are hopes for health care, or red, biotechnology to open up new ways to prevent, treat and cure so far incurable diseases using new methods of treatment and diagnosis. Biotech medicines such as proteins, antibodies and enzymes now account for 20% of all marketed medicines and 50% of those in clinical trials. Biotechnology is also increasing the number of disease targets for conventional drug therapy. Today conventional drugs target fewer than 500 diseases, but in the future this is likely to rise to between 5 000-10 000 targets.

Through genetic engineering, biotechnology also uses other living organisms, such as plant and animal cells, viruses and yeasts, to assist in the large-scale production of medicines for human use (bio manufacturing).

The health care areas in which biotechnology is currently being used include medicines, vaccines, diagnostics and emerging cell and gene therapies. The aim is to create both comprehensive and highly individualised medicines, as well as move from treatment towards disease prevention and cure.

Europabio classifies the following categories as belonging to red biotechnology (EuropaBio 2005):

- Cell and tissues
- Stem cells
- Gene therapy
- Orphan drugs and rare diseases
- Proteomics
- Pharmacogenetics
- Diagnostics
- Genetic testing

The definitions of red, white and green biotechnology are not mutually exclusive, and the groups with their subclasses are not easily intercomparable; they could rather be seen as classifications stemming from different aspects of production. Green biotechnology refers to techniques and applications that concerns plants; consequently, it could be seen as connected to the raw material source of the application. White biotechnology refers to techniques that offer a biotechnological solution to industrial processes or specific parts thereof. It is typically a new way of producing existing products, and could preferably be compared to conventional methods of production. Health care or red biotechnology is clearly a definition based on the application area, irrespective of the raw material or the process used.

Most of the groups are closely intertwined, and the different categories can benefit from more or less common basic technologies. This also suggests that the nomenclature in the field of biotechnology is somewhat unstructured, which according to our survey can cause confusion even among biotechnologists themselves. The intricate definitions also increase the risk of information asymmetry between different parties in biotechnology.

In a strive for best possible distinctness and highest transparency, we have throughout our survey chosen to use the OECD guideline for the statistical definitions of biotechnology and its subgroups (OECD 2005). Table 2.4 shows the indicative but not exhaustive list of biotechnologies.[4]

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[4] Also the OECD definitions are, however, overlapping. For example, "DNA (the coding)" has a subgroup "genomics". Genomics has been defined as "Generation of information about living things by systematic approaches that can be performed on an industrial scale", which includes a wide array of technologies and research fields (Brent 2000). The Medical Subject Headings (MeSH) defines genomics as "The systematic

Table 2.4 The indicative but not exhaustive list of biotechnologies as presented by OECD (OECD 2005)

DNA (the coding)	genomics pharmaco-genetics gene probes DNA sequencing/synthesis/amplification genetic engineering
Proteins and molecules (the functional blocks)	protein/peptide sequencing/synthesis lipid/protein glyco-engineering proteomics hormones and growth factors cell receptors/signalling/pheromones
Cell and tissue culture and engineering	cell/tissue culture tissue engineering hybridisation cellular fusion vaccine/immune stimulants embryo manipulation
Process bio-technologies	bioreactors fermentation bioprocessing bioleaching biopulping biobleaching biodesulphurisation bioremediation biofiltration
Sub-cellular organisms	gene therapy viral vectors
Other	*not specified*

study of the complete DNA sequence (GENOME) of organisms", and puts proteomics ("The systematic study of the complete complement of proteins (PROTEOME) of organisms") as a subgroup of genomics (MeSH 2001, MeSH 2003).
Proteomics again is defined as "…not only the identification and quantification of proteins, but also the determination of their localization, modifications, interactions, activities, and, ultimately, their function. … The explosive growth of this field is driven by multiple forces –genomics and its revelation of more and more new proteins; powerful protein technologies, such as newly developed mass spectrometry approaches, global [yeast] two-hybrid techniques, and spin-offs from DNA arrays; and innovative computational tools and methods to process, analyze, and interpret prodigious amounts of data." (Fields 2001). Thus, within DNA (the coding) we have moved to the sub-areas of proteins and molecules, further to cell and tissue culture and engineering, and back to DNA (the coding).

In the following section we will in more detail explain the nomenclature suggested by OECD, and look at how each technology is utilised by companies in the respective areas of application.

2.3.3 DNA (the Coding)

DNA not only forms the core of life, but also the core of modern biotechnology. The majority of modern biotechnological applications are based on knowledge and technologies derived from studies concerning DNA. This is reflected in the results showing that techniques classified under DNA (the coding) are abundantly used in all commercial application areas (Figure 2.3).

Especially after the development of techniques such as microarrays and the polymerase chain reaction (PCR), the amount of extracted information has grown exponentially. **Bioinformatics** is involved in processing this data towards meaningful applications. It seems also intuitive that diagnostics and modern drug development, as well as **devices,** utilise or are closely connected to DNA techniques; many diagnostic applications are based on the direct detection of DNA or RNA strands. The preponderance among forestry applications in our data is explained by the analytical strength offered by the DNA techniques; studying the genotype offers significant time savings compared to studying the phenotypes.

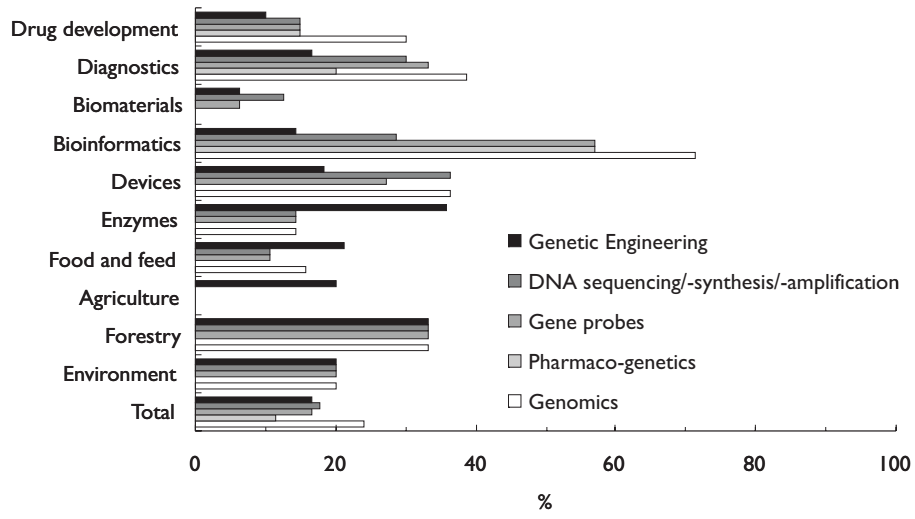

Figure 2.3 Commercial application areas and biotechnologies related to the DNA coding

2.3.4 Proteins and Molecules (the Functional Blocks)

Proteins and molecules are constructed in a living cell according to information extracted from the DNA/RNA codes. **Proteomics** and glycomics are regarded as the following steps in the cascade of genetic information, exhibiting a strongly increasing complexity, and requiring a wide array of assay tools (Hirabayashi and Kasai 2000, Fields 2001). **Lipid/protein engineering** and proteomics are especially used in the health care related application areas, whereas food and feed related applications utilise all but those technologies (Figure 2.4).

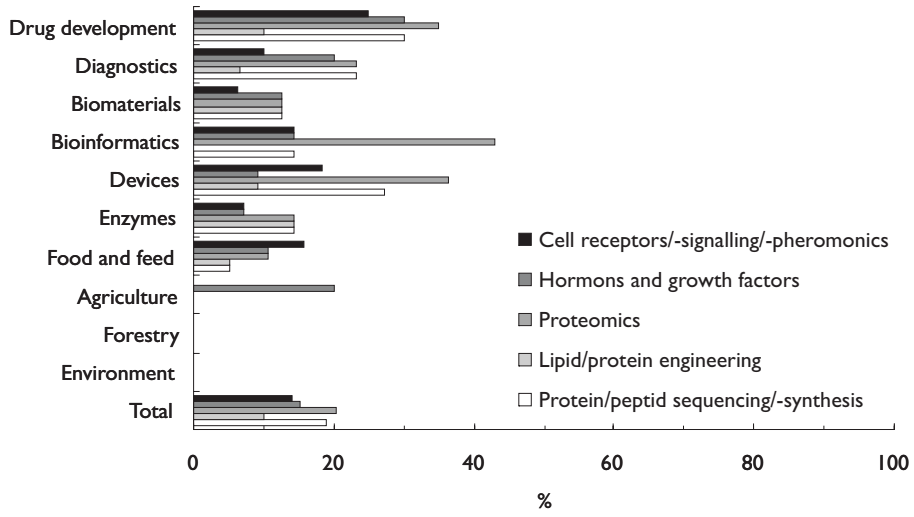

Figure 2.4 The fields of commercial applications and technologies related to functional blocks of proteins and molecules

2.3.5 Cell/Tissue Culture

Tissue engineering was coined at a National Science Foundation sponsored meeting in 1987, and later defined as "…the application of principles and methods of engineering and life sciences toward fundamental understanding … and development of biological substitutes to restore, maintain and improve [human] tissue functions (Sittinger *et al.* 2005, ETES 2005, NSF 2005, TESI 2005). Applications are found particularly in biomaterials, but also in other fields of health areas, as well as devices.

Common technologies in **hybridisation** are northern and southern blot (hybridisation), and **embryo manipulation** can be performed in embryos originating both from animals and humans, with major ethical considerations especially around [human] stem cell research. **Cellular fusion** technology might constitute a new means for gene therapy in the future (Daley 2004). These techniques seem to be relatively evenly used in the field of health care, but not in other application areas (Figure 2.5).

Finally, **vaccines/immune stimulants** are used in health care related applications.

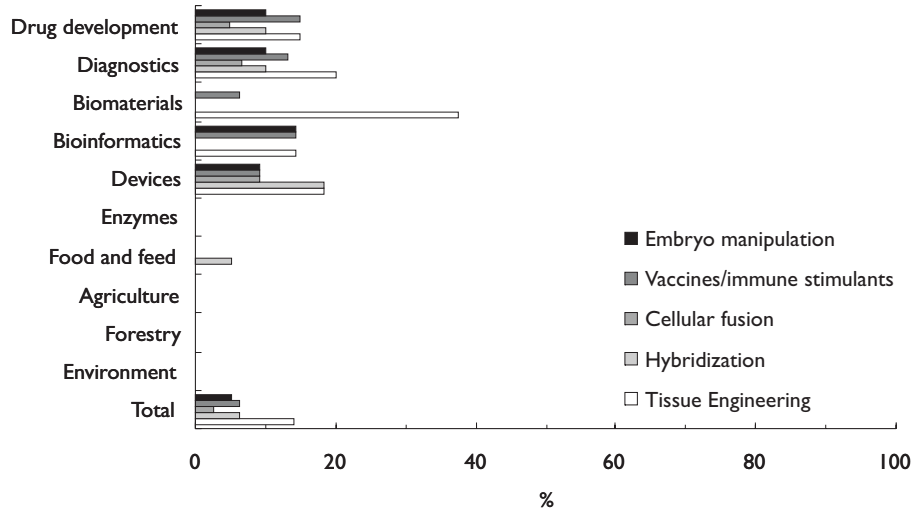

Figure 2.5 The fields of commercial applications and technologies related to cell and tissue cultures

2.3.6 Process Biotechnologies

Process biotechnologies emerged largely with the uncovering of the molecular details of cell processes. They can be applied in a variety of settings, ranging from the manufacture of human insulin to biodegradable plastics, and laundry detergent enzymes to hepatitis B vaccine. Typically, the technology used comes from other areas of biotechnological research and development, but the industrial scale setup is achieved though specific knowledge in bioprocessing. An example is the combination of microbial fermentation with recombinant DNA technology. The distinction between process biotechnology and other techniques can be hard to establish.

The main application areas of process biotechnology are usually found within agriculture, forestry, enzymes and food and feed. Energy production and energy saving applications, as well as environmental issues, are under special focus in Finland, and biotechnology-based process enhancements can also be utilized in drug manufacturing (Söderlund 2005, VTT 2005).

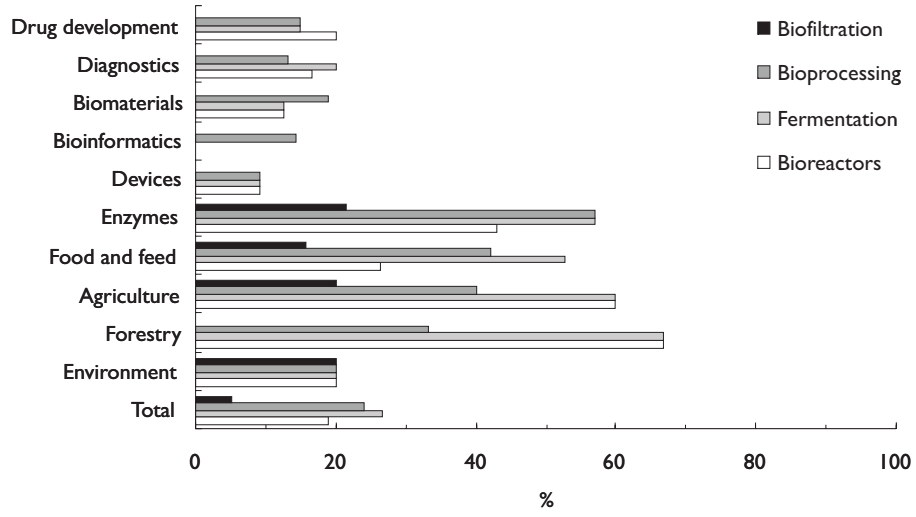

Figure 2.6 The fields of commercial applications and technologies related to process biotechnologies

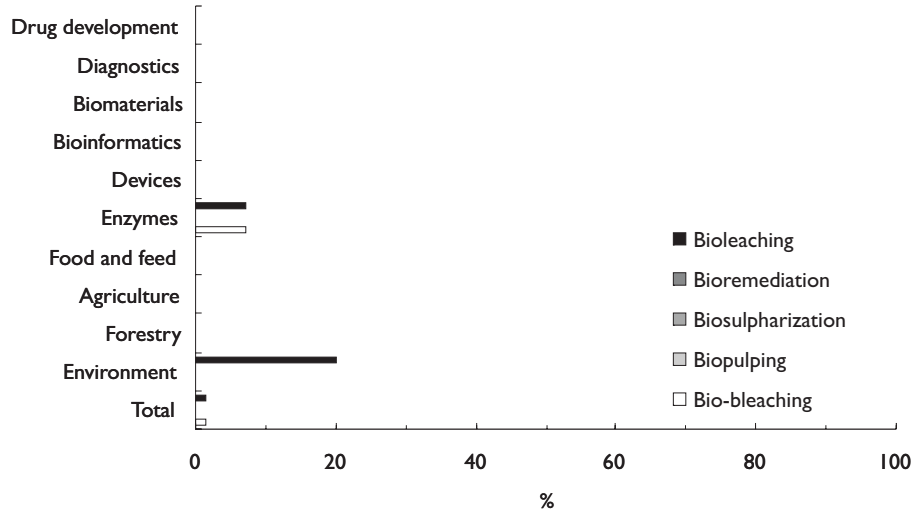

Figure 2.7 The fields of commercial applications and technologies related to process biotechnologies

Our data show that bioreactors, fermentation, bioprocessing, and to a lesser extent biofiltration, are used in all major application areas of biotechnology (Figure 2.6). The other technologies are only incidentally applied (Figure 2.7). Biopulping, biobleaching, bioleaching and also bioremediation usually have very specific application areas, and the respective companies might not belong to the classification biotechnology SMEs. Examples are the large forest and energy companies (Department of Energy 2005, Moreira *et al.* 2005, Dyadic 2002, Holder, Stanek and Harvey 2002)

2.3.7 Sub-Cellular Organisms

Gene therapy encompasses at least four types of application of genetic engineering for the insertion of genes into humans: somatic cell gene therapy, germ line gene therapy, enhancement genetic engineering and eugenic genetic engineering. Somatic cell engineering is technically the simplest, and human clinical trials have been started for the treatment of diseases, such as severe immunodeficiencies, many types of tumours (e.g. melanoma, prostate, ovarian, brain and lung cancer), AIDS and cardiovascular disorders. Germ line cell therapy is both technically and ethically more challenging, and enhancement genetic engineering, as well as eugenic genetic engineering, present significant and troubling ethical concerns in addition to the technical issues. (Anderson 1985, Anderson 1992)

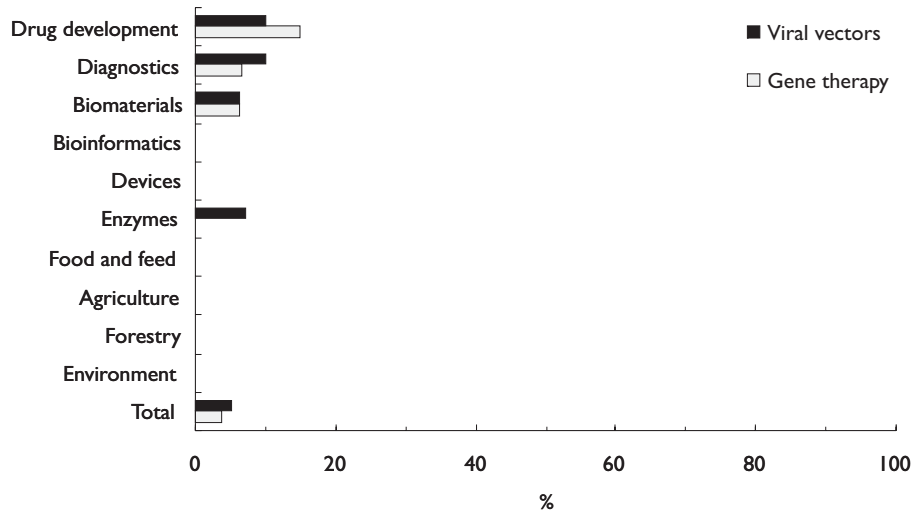

Figure 2.8 The fields of commercial applications and technologies related to sub-cellular organisms

Viral vectors are usually associated with gene therapy, where the viral vector is used to introduce the foreign DNA into the cell. However, viral vectors can also be used in the study of, for example, plant cells.

Figure 2.8 shows a connection between gene therapy and viral vectors, which seems logical also from a technological point-of-view. The application areas are found within the field of health care. The connection to enzyme applications remains somewhat unclear; it could also refer to intracellular enzymes such as ribonucleases, instead of industrial enzymes as defined in the process biotechnology sector.

2.4 Financial Resources

Small and medium-sized Finnish biotechnology companies rely on equity for 64.5% of their financing when sales earnings are not included in the calculations. However, they also rely relatively heavily on capital loans, comprising 25.1 % of the total funding. For Finnish SMEs in general capital loans are a very marginal funding source with just 1.9 % in 2001. Capital loans are more expensive than conventional debt but do not have to be paid back if there are no profits. Capital loans are therefore more suitable for companies operating in high-risk investment projects such as the biotechnology sector. The relative importance of capital loans over debt is noticeable, as biotechnology SMEs rely on debt only for 10.3 % of their funding.

2.4.1 Equity Financing

Equity financing is the main financial instrument of the small and medium-sized biotechnology companies in Finland. The Finnish companies have obtained 233 million euros in equity from their owners (Table 1.6). The largest owner group is **private venture capital companies** with a 27 % share of the companies' total equity. **Companies' personnel and external individuals** (combined to form the class **Individuals** in the following tables) form the second largest owner group with a 24 % ownership share. **State venture capital institutions** also form a significant group of players in the field. The most active player has recently been Sitra, the Finnish National Fund for Research and Development, the ownership share of which is almost 15 % of the biotechnology SMEs' equity. **Other companies** own over 17 % of the industry.

Ownership structure by human capital

Company's personnel and external individuals own the largest share of the micro-sized Finnish biotechnology companies employing fewer than 10 employees (Table 2.5). In medium-sized companies with 10 or more employees, **private venture capital companies** have invested the largest share in terms of equity financing. The equity financing seems to have enabled the growth of the companies, since 95 % of the financing has been directed at companies with 10 or more employees at the end of 2003.

Table 2.5 Ownership structure by human capital (HC)[5]

HC variables	Individuals	State VC	Private VC	Other companies	Other	**Total**
Personnel < 10 (n=30)	1.8 %	1.1 %	0.8 %	1.1 %	0.0 %	**4.9 % (11.4 mill eur)**
Personnel ≥ 10 (n=37)	22.3 %	17.7 %	26.4 %	16.3 %	12.3 %	**95.1 % (221.7 mill eur)**
Doctors per personnel < 22% (n=32)	18.4 %	6.7 %	21.0 %	16.3 %	4.3 %	**66.7 % (155.5 mill eur)**
Doctors per personnel ≥ 22% (n=35)	5.7 %	12.1 %	6.3 %	1.1 %	8.1 %	**33.3 % (77.6 mill eur)**
Total	**24.1 %**	**18.9 %**	**27.3 %**	**17.4 %**	**12.4 %**	**100.0 % (233.1 mill eur)**

[5] Our sample with full information on the sources of financing contains 67 companies. The sample is weighted to match the population (see also Hermans and Tahvanainen 2002). We used the following definition for equity: Equity equals the stockholders' paid-in equity capital and equity reserves obtained from National Board of Patents and Registration of Finland. We ignored the cumulative profits of past financial years. This is due to the idea that even when companies' balance sheets are distorted by great losses, they do not necessarily reflect the level of expected earnings. Negative equity figures distort also the counting of equity shares. If we take official paid-in capital figures on stockholders' equity we get the value that stockholders have invested in a company. Accordingly, we do not consider earnings as part of equity financing in this study.

However, the preferences of the distinctive investor groups seem to differ in accordance with the level of education of the company's human capital. **State venture capital institutions**, mainly Sitra, and the group of **other Investors** have preferred to invest in companies with a large share of exceptionally highly educated personnel. By contrast, **other companies**, **private venture capital companies** and **individuals** have mostly directed their investments to companies with smaller doctor-to-personnel ratios.

Ownership structure by structural capital

We measured Intellectual Property Rights (IPRs) as the number of patent applications and patents (Table 2.6). **Investors** have invested almost 94 % of total equity in the companies with 4 or more patents and applications in their patent portfolios. **Individuals** own the largest share of the companies with small patent portfolios.

Table 2.6 Ownership structure by structural capital (SC)

SC variables	Individuals	State VC	Private VC	Other companies	Other	**Total**
IPRs < 4 (n=32)	2.6 %	1.5 %	1.6 %	0.6 %	0.1 %	**6.4 % (14.9 meur)**
IPRs ≥ 4 (n=35)	21.5 %	17.3 %	25.7 %	16.8 %	12.2 %	**93.6 % (218.2 meur)**
IPRs per personnel < 0.3 (n=32)	13.2 %	3.7 %	3.0 %	12.0 %	4.9 %	**36.7 % (85.6 meur)**
IPRs per personnel ≥ 0.3 (n=35)	11.0 %	15.1 %	24.3 %	5.4 %	7.5 %	**63.3 % (147.5 meur)**
Total	**24.1 %**	**18.9 %**	**27.3 %**	**17.4 %**	**12.4 %**	**100.0 % (233.1 meur)**

When we use patents and the patent applications-to-personnel ratio, the scheme changes. **Individuals** and **other companies** hold the largest share of those biotechnology companies that have a relatively small IPR-to-personnel ratio; and **state venture capital institutions** and **private venture capital companies** have directed their investments to the companies with a higher IPR intensity.

Ownership structure by relational capital

Other companies have focused their equity financing most clearly on those companies, whose sales have reached relatively high volumes; or, alternatively, they have been able to strengthen the exporting skills of the companies they own. International trade volumes seem to go quite closely hand in hand with international R&D collaboration. There are only 21 companies, 31 % of the companies in our sample, which collaborate with foreign universities, but these have obtained over 70 % of total equity financing (Table 2.7).

Table 2.7 Ownership structure by relational capital (RC).

RC variable	Individuals	State VC	Private VC	Other companies	Other	Total
Sales < 170000 (n=30)	5.0 %	3.9 %	3.6 %	1.1 %	1.5 %	**15.3 % (35.6 mill eur)**
Sales ≥ 170000 (n=37)	19.2 %	14.9 %	23.7 %	16.3 %	10.9 %	**84.7 % (197.6 mill eur)**
No R&D collaboration with foreign university (n=46)	6.6 %	7.4 %	9.1 %	4.3 %	1.8 %	**29.2 % (68.0 mill eur)**
R&D collaboration with foreign university (n=21)	17.5 %	11.4 %	18.2 %	13.1 %	10.6 %	**70.8 % (165.1 mill eur)**
Total	**11.8 %**	**14.7 %**	**27.3 %**	**17.4 %**	**12.4 %**	**100.0 % (233.1 mill eur)**

2.4.2 Capital Loan Financing

Capital loans are loans that satisfy the regulations enacted in the Finnish Companies Act. The act states that capital loans must be included in the shareholders' equity in the financial statement. In other words, capital loans are a mixture of the financial instruments of debt and equity. Capital loans can be used to prevent a company from being declared bankrupt, because they are defined as equity capital in the balance sheet despite their debt-like nature. Thus, the increase of capital loans compensates for past losses as a supplement to equity capital.

Capital loan structure by human capital

The small biotechnology industry has obtained over 90 million euros in capital loans constituting 25.1 % of total funding (Table 2.8). Thereby it is an important backbone, vital for company survival. The largest single capital loan provider is Tekes, the National Technology Agency of Finland.

Table 2.8 Capital loan structure by human capital (HC)

Capital loan structure by human capital (HC)									
	Domestic banks	State VC	Domestic private VC	Foreign VC	Other Compa-nies	Finnvera	Tekes	Others	**Total**
Staff (n < 10)	0.0 %	4.8 %	0.7 %	0.7 %	0.9 %	0.2 %	2.6 %	0.0 %	**10.0 % (9.1 mill eur)**
Staff (n ≥ 10)	2.1 %	10.0 %	0.7 %	0.2 %	2.8 %	4.7 %	61.0 %	8.4 %	**90.0 % (81.7 mill eur)**
Doctors per personnel < 22%	1.6 %	10.7 %	0.7 %	0.2 %	2.3 %	3.5 %	8.1 %	0.1 %	**27.2 % (24.7 mill eur)**
Doctors per personnel ≥ 22%	0.6 %	4.1 %	0.7 %	0.7 %	1.4 %	1.5 %	55.5 %	8.4 %	**72.8 % (66.1 mill eur)**
Total	**2.2 %**	**14.8 %**	**1.5 %**	**0.9 %**	**3.7 %**	**4.9 %**	**63.5 %**	**8.4 %**	**100,0 % (90.8 mill eur)**

Tekes has provided the biotechnology companies with nearly 60 million euros in terms of capital loans. Tekes invests typically in research-intensive projects, whereas other companies invest in the projects which are already closer to markets. Thus, the projects closer to markets employ human capital related to other competencies rather than solely to academic research.

Capital loan structures by relational capital and structural capital

Tekes's acknowledged stance towards the concept of a well-balanced intellectual capital base as a key success factor for knowledge-intensive organisations restates itself in the distributions of capital loan sources by the two remaining IC components. Tekes clearly prefers companies that display higher levels of structural and relational capital (Tables 2.9 and 2.10).

Table 2.9 Capital loan structure by structural capital (SC)

Capital loan structure by structural capital (SC)									
	Domestic banks	State VC	Domestic private VC	Foreign VC	Other Compa-nies	Finnvera	Tekes	Others	**Total**
IPR < 4 pcs	0.0 %	4.3 %	1.5 %	0.2 %	0.5 %	0.5 %	4.4 %	0.1 %	**11.5 % (10.5 mill eur)**
IPR ≥ 4 pcs	2.2 %	10.5 %	0.0 %	0.7 %	3.2 %	4.4 %	59.1 %	8.4 %	**88.5 % (80.3 mill eur)**
IPR/Staff < 0.3	1.5 %	6.2 %	0.7 %	0.2 %	2.8 %	0.3 %	17.4 %	7.5 %	**36.7 % (33.3 mill eur)**
IPR/Staff ≥ 0.3	0.6 %	8.6 %	0.7 %	0.7 %	0.9 %	4.6 %	46.1 %	1.0 %	**63.3 % (57.4 mill eur)**
Total	**2.2 %**	**14.8 %**	**1.5 %**	**0.9 %**	**3.7 %**	**4.9 %**	**63.5 %**	**8.4 %**	**100,0 % (90.8 mill eur)**

Table 2.10 Capital loan structure by relational capital (RC)

Capital loan structure by relational capital (RC)									
	Domestic banks	State VC	Domestic private VC	Foreign VC	Other Compa-nies	Finnvera	Tekes	Others	**Total**
Sales < 170,000	0.6 %	12.3 %	0.7 %	0.7 %	0.9 %	1.4 %	44.2 %	8.4 %	**69.3 % (62.9 mill eur)**
Sales ≥ 170,000	1.5 %	2.5 %	0.7 %	0.2 %	2.8 %	3.6 %	19.3 %	0.1 %	**30.7 % (27.9 mill eur)**
No collabo-ration with foreign university	1.6 %	8.9 %	1.5 %	0.2 %	1.4 %	0.9 %	13.2 %	7.5 %	**35.2 % (32.0 mill eur)**
Collabora-tion with foreign university	0.6 %	5.9 %	0.0 %	0.7 %	2.3 %	4.0 %	50.4 %	1.0 %	**64.8 % (58.8 mill eur)**
Total	**2.2 %**	**14.3 %**	**1.5 %**	**0.9 %**	**3.7 %**	**4.9 %**	**63.5 %**	**8.4 %**	**100,0 % (90.8 mill eur)**

Except for Finnvera that seems to follow a capital loan strategy similar to Tekes, no such obvious investment policies can be observed by other capital loan providers. It seems clear that a higher amount of IPRs is strictly related to capital loans invested in the companies. This is rather intuitive, since IPRs are traditionally considered a simple (and often sole) indicator of innovativeness and commercialisation potential in practice underlying positive funding decisions.

2.5 Conclusions

In the present chapter we presented descriptive findings of the ETLA survey conducted at the end of 2004. Together with the conclusions of results derived from the ETLA 2002 survey, the findings outline the current state of the Finnish biotechnology industry with a few essential key figures. These serve as an introductory overview of the industry and pave the way for more analytical approaches to specific issues to be dealt with in the course of the following chapters.

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CHAPTER 3

How do You See the Future Prospects of the Finnish Biotechnology Industry? – Interviewing 89 Business Leaders

Hussi, Tomi – Hermans, Raine – Kulvik, Martti
– Tahvanainen, Antti-Jussi

3 How do You See the Future Prospects of the Finnish Biotechnology Industry?

3.1 Introduction

The public discussion on the Finnish biotechnology industry has reflected differing opinions on the overall opportunities and threats related to the industry. However, there has been no systematic survey on the views provided by all the biotechnology leaders. For this reason, we interviewed 89 business leaders asking how they see the future prospects of the Finnish biotechnology industry. Their answers were analysed qualitatively and classified in four categories: strengths, weaknesses, opportunities and threats (SWOT).

The SWOT classification divides the time horizon into the short term and the long term. Strengths and weaknesses address the short-term prospects, which are mainly based on the present state of the biotechnology industry. Opportunities and threats are based on wider megatrends, which extend their impact on the long-term development. Our interviewees mentioned some issues that were held critically important for both the short and long term competitiveness of the industry. Similar overlapping occurred

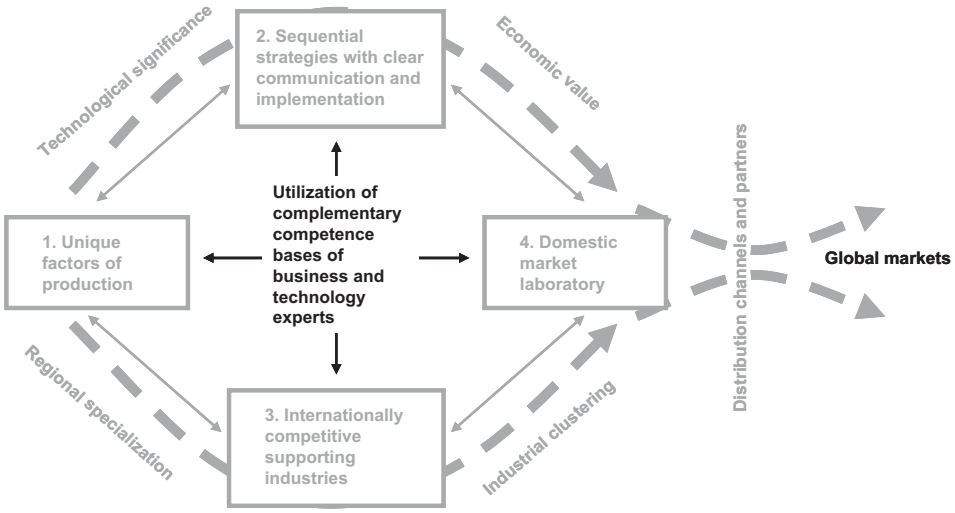

Figure 3.1 The company leaders' central role within the dynamic strategy framework

when some issues were held very positive, on one hand, and extremely negative on the other. Therefore, our classification of the short term strengths and weaknesses and also long term opportunities and threats is partially overlapping. This has led us to treat some of the issues repeatedly in the discourse of this chapter, albeit from various different angles.

The opinions of company leaders provide an important basis for the analysis and strategic implications, as well as a description on how effectively competencies are utilised (Figure 3.1). There are several aspects that were helpful in our strategy construction. For instance, the leaders see that the scientifically competent people are a key resource of the Finnish biotechnology industry, but at the same time there seems to be a severe lack of competent business leaders. This calls for finding quick and efficient solutions to creating a market-place for business competencies for this science-based sector. Chapter 6 provides some suggestions for dealing with the issue. Swift action seems critically important in the present situation, in which a great deal of leaders disclose the above mentioned lack of business competence as a weakness while simultaneously regarding the financing system as an even more severe weakness. This raises questions: is there really a lack of money, or is there merely a lack of solid market-oriented business models that would attract potential financiers?

3.2 Theoretical Background

The logic of business is shifting from mass-production to production of highly differentiated and knowledge-intensive goods and services. One recent theoretical construction to tackle this topical issue is the concept of intellectual capital. The biotechnology sector is evidently a knowledge-intensive industry and therefore utilisation of the intellectual capital framework is a well argued approach for analysing its current prerequisites and future development trends. Edvinsson and Malone (1997) discuss the significance of intellectual capital to a company. The essence of the discussion is the ability to give a holistic view on organisational development.

Usually, intellectual capital is defined as consisting of three elements, human, structural and relational capital. Intellectual capital provides a framework enabling all of these dimensions to be viewed in relation to each other. Even when two dimensions are very strong, the weak or inadequately managed third dimension of the value platform model presented in Figure 3.2 disrupts the value creation process. According to the model, it is the intersection of all three dimensions that forms the basis for value creation (Saint-Onge *et al.* in Edvinsson and Malone 1997). Knowledge management

can be seen as a force pulling distinctive dimensions into closer interaction with each other. The merit of the intellectual capital platform is that three central dimensions of organisational development activities are considered in a single comprehensive framework emphasizing the importance of their balanced interaction (Mouritsen *et al.* 2000).

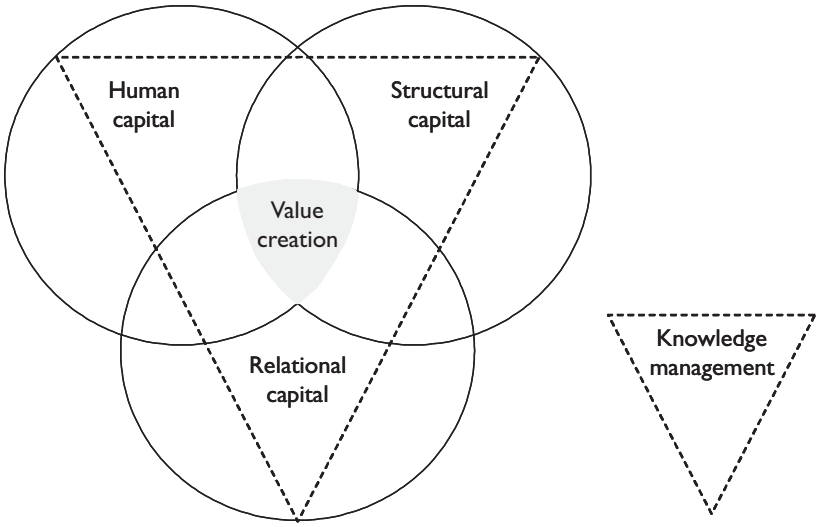

Figure 3.2 The value platform model

In the following we will shortly describe each of the three dimensions forming the concept of intellectual capital. For further discussions, see MERITUM project (2002), Bontis (2002) and references therein.

Human capital

Human capital is defined as the individual's knowledge, experiences, capabilities, skills, creativity and innovativeness (Edvinsson and Malone 1997). These are interconnected and collectively contribute to success in work (Ranki 1999). Sveiby (1997) uses the concept 'employee competence', which he defines as the capacity to act in different situations to create both tangible and intangible assets.

The ability to perceive changes in the operational environment is also included in human capital (Edvinsson and Malone 1997). Learning is an individual's development: an adaptation to a changing environment or a po-

tency to change the environment. These changes require the ability to control immediate work tasks, as well as the ability to improve operations and a readiness to develop even qualitative features of work (Salmenperä *et al.* 2000). Attitudes are related to this readiness, because they show what kind of stance a person takes towards his or her tasks (Mayo and Lank 1994).

The fact that a company cannot own its human capital distinguishes this dimension of intellectual capital from the other company resources (Edvinsson and Malone 1997). Uncertainty about an employee's commitment to the organisation reduces the organisation's willingness to make these investments, especially if the required skills are non-specific and transferable (Albert and Bradley 1997). Yet, competent personnel are the key to a company's endeavour to realise and develop its business ideas (Hansson 2001, Sveiby 1990). Investments in personnel are as crucial for knowledge-intensive companies as a mass producers' investments in tangible assets (Sveiby and Lloyd 1987).

Structural capital

Structural capital includes patents, concepts, models, computer and administrative systems, and organisational culture (Sveiby 1997). Edvinsson and Malone (1997) define structural capital as

- the context,
- empowerment of employees,
- structures supporting human capital,
- organisational capital,
- innovation capital and
- process capital.

Empowerment of the employees is based on distributed decision-making and collaborative leadership models, aimed at inducing employees to commit to the organisation and its goals.

Structures that support human capital include, for example, recruiting capabilities, organisational culture, development activities and motivating strategies.

Organisational capital consists of systems and tools, enhancement of knowledge flows and organisational competence.

Innovation capital includes a company's renewal capability, results from innovativeness protected by intellectual property rights, as well as results that can be used to create new products and services and bring them quickly to the markets.

Process capital is practical knowledge including definitions and improvements of work and production processes. (Edvinsson and Malone 1997).

An organisation's knowledge base accumulates from numerous daily decisions and experiences. These are stored in work processes, instructions, forms etc. resulting in organisational learning. Organisational culture can be seen as a consequence of organisational learning as it forms a shared framework for defining and solving problems. Schein (1992) connects organisational culture with leadership and defines them as different sides of the same coin.

According to Edvinsson and Malone (1997) structural capital includes all the codified knowledge and organisational structures a company has created by its human capital, or otherwise acquired for the organisation. Organisational structure, different documents and all intellectual property rights (patents, trademarks, copyrights etc.) are included in the structural capital. Unlike human capital, the company owns its structural capital and, therefore, it is also able to sell specific parts of it, such as databases.

Relational capital

The relational capital includes relationships with customers and suppliers and the company's collaboration networks (Edvinsson and Malone 1997, Sveiby 1997, Stewart 1998). For instance, concepts such as customer capital, networking and virtual organisations have been associated with relational capital.

Customer capital consists of the strength and loyalty of the customer relationship. Such characteristics as satisfaction, durability, price-sensitiveness and good financial performance of long-term customers are related to this category (Edvinsson and Malone 1997). Customer capital can be created by committing the customers to the company's activities using time and resources. An enduring and trustful relationship between the seller and the customer is the key element. Relationships are judged based on penetration, coverage and loyalty measured as a customer's probability of continuing the partnership (Stewart 1998).

Interdependence is claimed to be a characteristic of technology-based firms (Yli-Renko 1999). Even though networking is seen as beneficial to a company, it has multifaceted effects on the company. Breaking up a commitment to some relationships and building up new ones can result in significant costs; reluctance to accept these costs reduces a company's mobility in its relationships and may hinder its innovativeness (Håkansson and Ford 2002).

Due to the increasing need for networking, organisational boundaries lose significance. Collaboration leads to co-operative systems, such as virtual organisations lasting at least for a while. Therefore, competition no longer exists merely among different companies, but also between different value chains. The latter consist of suppliers, middlemen, service providers and manufacturers. Information technology can be used to improve the functioning of the value chain both inside organisations and between them (Salmenperä *et al.* 2000).

3.3 Data and Methods of the Study

Telephone interviews

The ETLA 2004 survey includes information on 87 biotechnology companies in autumn 2004 and interviews of the respondents. The survey was conducted as a telephone interview. The last question was open and thus diverged from the more formal structure of other questions that prompted for a numeric answer or suggested several possibilities the respondent could choose from. The respondents were asked how they view the future prospects of the Finnish biotechnology industry. The respondent was allowed to discuss the matter freely. If the respondent stressed only the negative (positive) prospects they were asked if there were any positive (negative) prospects, and how both those prospects would become reality in the future. If the respondent had difficulty forming an overall view, the interviewer related the discussion to SWOT: what are the potential strengths and weaknesses of the Finnish biotechnology industry in the short term, or opportunities and threats in the long term. Thus the SWOT framework was already an essential element of the interviews at the beginning of the research process.

Sequential method

The analysis of the qualitative data was conducted sequentially in order to process the data into manageable categories. The starting point of the analysis was to divide all data into the four categories of a SWOT approach (strengths, weaknesses, opportunities, threats). Next, the four categories were further scrutinised to find general themes in each category. This phase resulted in a set of 8 subcategories for the short-term factors and 13 subcategories for the long-term factors.

In the third phase of the analysis, the subcategories were reorganised following the intellectual capital framework presented above. The intellectual capital categorisation was linked back to the original SWOT approach by focusing on the different time perspectives, namely short-term [strengths and weaknesses] and long-term [opportunities and threats] (Figure 3.3).

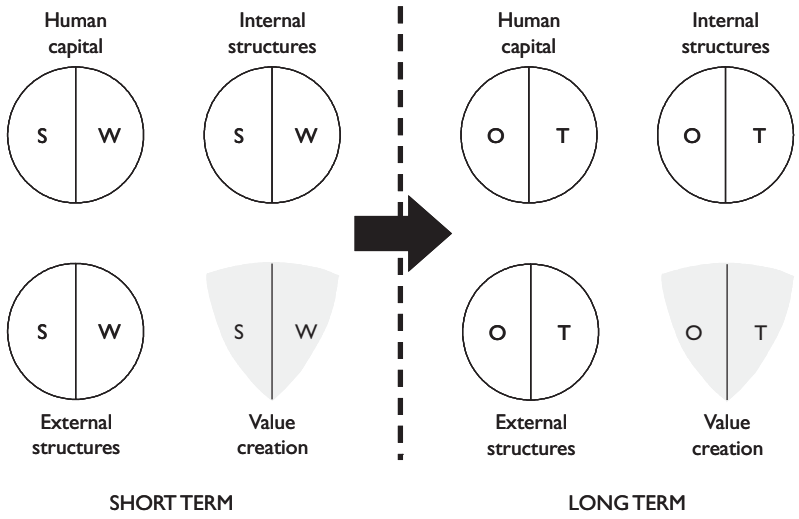

Figure 3.3 The research strategy

Quantitative distribution of leaders' opinions

Scientific competence seems to be the most significant base for the Finnish biotechnology industry according to the number of respondents who mentioned it as a strength (Figure 3.4). The business leaders seem to be satisfied with the activities performed by Tekes and the overall public support. However, almost two thirds of the respondents consider the Finnish financing system a serious weakness. The leaders of the companies with posi-

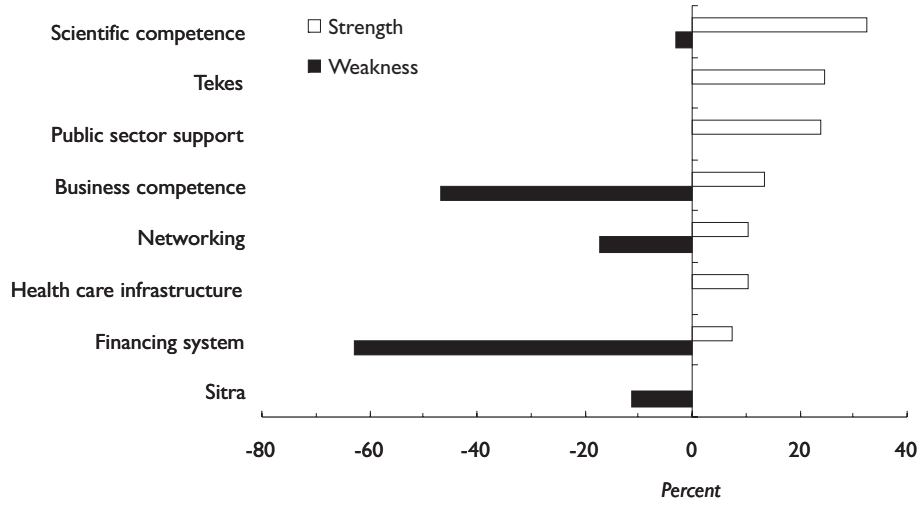

Figure 3.4 Short-term strengths and weaknesses

tive cash flows consider the financing system to be a clear strength that the industry can benefit from. Their companies were able to finance their product development activities by their earnings from sales. Business competence was considered a weakness within the industry by half of the leaders.

Almost 30 % of the biotechnology leaders seem to be significantly optimistic about the long term future prospects, whereas only 13 % of the leaders view the prospects negatively (Figure 3.5). Almost 30 % of the leaders

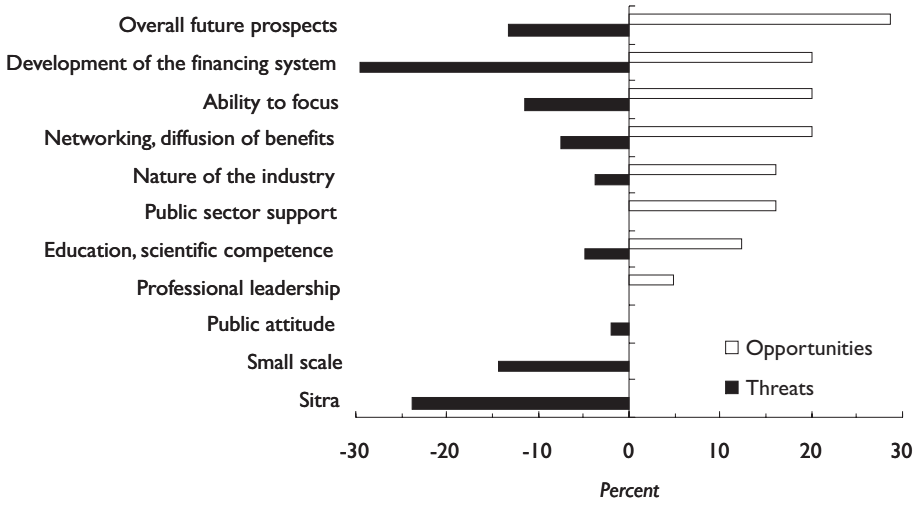

Figure 3.5 Long-term opportunities and threats

see the development of the financing system as a severe threat while every fifth leader sees the development of the financing system as a major opportunity. The negative attitudes are an expression of a worry over the long term impacts of short-sighted financing.

Networking and international collaboration are seen by 20 % of the leaders as a long term opportunity; however, some 7 % of the leaders see the outward diffusion of knowledge of their company as a severe threat. Consequently, there is a need for an effective IPR management.

The nature of the industry appears as an ambiguous issue to the leaders: 5 % fear that tightening competition reduces profitable business opportunities in the log term, whereas over 15 % believe that the industry's market potential is so high that it ensures long term prosperity of the entire business.

Almost 24 % of the biotechnology leaders brought up Sitra as a threat to the long-term prospects of the Finnish industry but no one mentioned Sitra's activities as a long-term opportunity. These and other dimensions are discussed in more detail below providing some examples and anonymous quotations.

3.4 Qualitative Assessment of the Data

This section is outlined according to the research strategy presented above. Firstly it compiles the views of the interviewed biotechnology leaders on the current situation of the biotechnology industry in Finland. Short-term strengths and weaknesses are divided into the categories of intellectual capital, *i.e.* human, structural and relational capital, respectively. In the next step the value creation potential from the intersection of the IC categories have been identified according to the intellectual capital framework.

Secondly, we have compiled the views on the long-term development trends based on identified opportunities and threats, subdividing them according to the IC framework. We want to stress that the data and views stem directly from the interviewed biotechnology leaders, and that we have used established methods and principles developed for analysis of qualitative data in our assessment (Eskola and Suoranta 1998, Mason 2002, Alasuutari 1994, Silverman 1998, Jensen 2002).

Our aim has been to retain the voice of the interviewees but minimize any possible internal or external noise. Section five concludes with our own interpretations of the data and the results.

3.4.1 Short-Term Strengths

About one third of the interviewees explicitly commented that they see the future of the biotechnology industry as somewhat bright. The technology base is seen as solid and the level of competence as good. Below, we describe in-depth the short-term strengths within each dimension of intellectual capital.

Human capital

The interview data shows that scientific competence is an essential strength of the Finnish biotechnology industry. Finnish education and basic research is recognised as being on a high level in an international comparison, and this explains the core of Finland's competitiveness in the biotechnology sector. There is a long tradition of academic life-science research resulting in high quality medical and clinical research. The well-functioning education system ensures that there are talented and committed people available for recruiting at a reasonable salary level. Finns are also known as reliable partners.

> *A: But somehow I feel that one competitive advantage of Finland is that we have a strong bio sector. I cannot say if it is the bio sector specifically, but at least a lot of people are trained in this field. (…) Well, at least there are many open job applications from people with a very good educational background and experience.*

According to the data there is also much knowledge about creating and patenting basic applications, such as molecules. High scientific competence is important because it is the source of innovations. The Finnish innovations are seen as original and competitive. This creates good conditions for the future of the biotechnology industry. The biotechnology industry is regarded as very knowledge-intensive, but not particularly capital-intensive. Some areas of particular strength mentioned in the data are pharmaceutical, biotechnological and medical competencies.

At a more detailed level the strengths lie particularly in pharmaceutical chemistry, brain research, molecular biology, genetic engineering of bacteria, biomaterials, genomics, proteomics, neurology and expertise on yeast and nutrition. There is also a high level of competence in related fields, such as chemistry and other relevant fields of natural sciences, as well as information and communication technology. This broad and in-depth technology base that combines a multitude of disciplines is regarded to be the foundation for making Finland a suitable country for developing a biotechnology industry.

In addition to purely scientific competencies, the business competencies stand out as a strength. The interviewees claim that Finnish biotechnology companies have been endowed with business competencies, because past experiences of numerous national companies working in the medical industry have built up a competence pool relevant enough for today's biotechnology companies to draw from it to their own ends. Even though these companies have merged into bigger Finnish and also foreign companies, this history has created management expertise in production, research and development and marketing. In this context, arguments about the lack of business competence are seen more as a sort of myth.

> *People say, of course, that the bio-industry lacks leaders and business competencies. There are dozens of companies here and all have CEOs, at least as far as I know. (…) At least people aren't queuing up to hire me. If there were a terrible shortage, one would imagine that 20 years of experience in the field would result in constant inquiries but this is not the case.*

It seems that the originating innovator is not necessarily the right person to be in charge when a company moves to a commercial phase in its lifecycle. A CEO, who also has profound industrial experience in terms of production can be an important asset. It is argued that there are potentially many managers with experience of industrial commercialisation in Finland because of success in the electronics industry.

> … *there is this strong electronics industry and they have this business competence about how to export products and create markets. I think that this is one area where expertise in management and commercialisation can be obtained. The other thing is, of course, that the specific characteristics of the biotechnology industry must be taken into account.*

Structural capital

Finland has many structural advantages that are ideal especially for research investigating the role of genes in the pathogenesis of diseases. First, people populating the eastern and northern parts of the country are genetically fairly homogeneous. Thus, identifying deviations in the genome that are potentially related to diseases is less difficult than in a population with a more heterogeneous gene pool. Second, Finland has a long history of accurate church registers that assist in the investigation of heredity of diseases. Furthermore, the Finnish culture is, in a way, a considerable strength, as Finns tend to actively participate in research projects. This willingness enables long-term follow-ups, in which multiple samples can be taken from the same patient over the course of time.

It is stated in the data that the collected Finnish genetic material is rather extraordinary due to its size. According to the interviewees, the accuracy of the Finnish patient register database is unique even on global scale. It has been compared to the Icelandic data banks, but the Finnish data might be in a class of its own. In combination with the extensive population register system it is possible to resolve family relationships and their role in the development of diseases. These strengths enable the search for gene-based diagnostics and other causal relationships. Finland has fifty years of research in the field, with numerous distinguished research groups. Therefore, Finland is seen to have a genuine competitive advantage in this field.

> *(…) if a certain disease modelling is connected to, let's say, a particular genome, then Finland has a sufficiently homogeneous population like Iceland, for example. So we can produce quality research in this area.*

The whole infrastructure of the health care sector results in various strengths useful to research purposes. The Finnish health care system creates ideal conditions for medical research because of high quality clinical expertise. Furthermore, the cost level is quite competitive compared to other Western countries. In Finland there are doctors who act both as a regular doctor and participate in research projects. The health care system produces large data sets that can be used for tracking down the gene-base of illnesses. Both education and the basic research system are at a high level.

The Finns' positive attitude towards research is seen as a rather exceptional feature in the interviews. The interviewees compared this with the United States and felt that similar attitudes are not encountered there. General consent makes it easier to undertake large clinical studies because volunteers are available. These strengths make Finland an excellent test market.

> *For example, the base of commercial success for our products has been created here. Finland's size is good for test marketing, and Finns are eager to try out new products. For example, Nokia would not be Nokia if it didn't have Finland. Because if you think how fast the cell phones penetrated the domestic market, the only reason is that a Finn is a highly unprejudiced experimenter. (…) So in Finland there is high quality research and it can be translated into a vernacular form so that people have the courage to try and understand what it is all about. And when they realise the advantage then it's quite easy to sell the product.*

The university facilities are up to date and there are constant investments in the very latest research equipment. Thus, the structures also support the high quality of research in Finland.

> *(…) how ultra-modern everything is. I mean I was just shocked when I came, I mean I went from San Diego, USA to London, England. London was like a third world country, everything falling apart, the labs were in a terrible state. And I came here and everything worked and was modern. This is a great country for science.*

Relational capital

Networking between different companies is seen as an essential success factor. According to many interviewees, the networking skills of the Finnish companies are rather good. Domestic networking is quite easy because practically everyone working in the field knows each other. The atmosphere for collaboration between universities, research institutes and companies is said to have improved considerably during the last couple of decades.

Networking is an essential element of business activities in this area. Companies specialising in research services, for example, provide an opportunity to outsource expensive laboratory infrastructure. Usually services are closely related to each other, and thus besides outsourcing the analytical services, manufacturing small sample production runs is also often outsourced. Collaboration with larger companies that already have an established position in the market is an important opportunity for smaller enterprises. Such collaboration can also facilitate the process of applying for funding, because established companies carefully screen the operations in which they participate. This lowers the entry threshold, because a well-known partner brings credibility to the project.

> *Well, it must be that the advantages that can be expected are clearly related to the development of the business activities. (…) certainly we are willing to join clusters because we are interested in external collaboration, since we are far too small on our own. In addition to wider range research competencies, we also need marketing and financial support…*

The support from the public sector is seen as an important strength because it is focused on the different phases of innovation. The interviewees feel the education system is excellent at creating new experts. The Academy of Finland coordinates funding for the universities through the Centres of Excellence system, and the national technology agency Tekes helps companies in their research and development programmes. Sitra, the Finnish National Fund for Research and Development, starts financing growing companies at an early stage. This system creates opportunities for small companies to enter the markets and also enables starting uncertain projects with sufficient volume that would not be funded otherwise.

The interviewees believe the public sector investments are a sound strategy for investing in the future. These can help create a new industry in Finland, as well as new jobs. Because the required investments are large and must be long-term, they would not be feasible for private venture capital organisations.

Public sector investments are seen as being especially beneficial in the first stages of innovation. The institutions that provide this funding are seen as quite competent to select the best candidates for funding, and long-term support keeps the companies viable. Besides financial support, public sector institutes can provide expert counselling and help build links to other investors. Their participation reflects the quality of the project. The public sector has also been active in terms of building an infrastructure for biotechnology.

The role of Tekes is especially praised in the data. Several interviewees note that they have a very positive impression of the institute. Because the biotechnology industry is so research- oriented, investments in the R&D projects make the role of Tekes a central one. Tekes is said to be active in the field and able to listen to different needs and direct its activities accordingly. The funding is sufficient to really help R&D projects and it encourages companies to focus on commercial opportunities. The expectations are seen to be reasonable and the bureaucracy is not wearisome.

A stable strategy makes Tekes a reliable partner. Tekes is also able to provide specialised guidance and training in essential topics, such as licensing. It also strongly supports networking between different companies and researchers. Some respondents even see that Tekes is currently the only serious and constantly focused financing institution in the sector, and that the Finnish biotechnology industry would not even exist without it.

> *… we did this Tekes project. Tekes provided marvellous support. (…) Well, if you can say that the project ended in two patent applications then you must be quite happy with it.*
>
> *And then we have Tekes, which I think is of primary importance, not only to biotechnology but the whole of Finnish industrial activity. But I think it is a sufficiently lean organisation to support this activity.*

Networking and training services are considered valuable because they help overcome different organisational boundaries. Researchers visiting companies for even short periods would help to build new insights into innovativeness and commercial opportunities. On the other hand, such visits also help to build personal contacts, which are beneficial to both researchers and companies.

> *(…) let's talk about the drug development branch, the researcher is able to work even for a short time period, a couple of months, in this kind of environment and in such a way, it would completely change the way this academic looks at things. If a person has been working ten to twenty years in the academic world, this practical training in the company world most certainly opens up different views on how little things can actually be innovated and commercialised.*

With respect to training there are opportunities to learn from experiences acquired by other industries. The IT sector has had many licensing deals and corporate acquisitions during the last decade. Some of the interviewees see that there are things in common that apply to both the IT industry and biotechnology. This would suggest that the biotechnology industry could learn from other branches.

> *(…) practices are so different in different countries. Going to the United States, they have their own way of licensing and sales and marketing. I would say that there should be more opportunities for those who are already familiar with the US practices, to share their knowledge and provide training. For example, there could be seminars related to the topic, where experienced people from Nokia would act as trainers.*

Many interviewees are quite happy with the way the public sector support institutions have been working. Even though not all expectations have been met, the interviewees see that the considerable investments in biotechnology were useful because it taught many important lessons. The recent experiences have led to a more critical look at projects, and the trend of raising expectations excessively is supposedly fading away.

> *This was an odyssey where state authorities burned money, but it taught us. The cost of the lesson was expensive but yet I think it was good that we did this. Certainly, I think it is excellent that we did this…*

Value creation

The data show that biotechnology companies face a bipolar setup with respect to the business strategy. In an ideal case, companies create internal revenues by providing services to customers while investing those into the development of eventually proprietary products. Business strategies that are aimed at early-stage sales and thus positive earnings make companies less dependent on the external sources of financing. The sustainable internal financing provides a solid foundation for more future-oriented research activities.

> *I am not familiar with the funding situation in Finland. Since we have organised our funding ourselves, we have not needed to look into that. So I must say that I do not know.*

The Finnish pharmaceutical industry is regarded as so international that there are sufficient skills to sell a promising product globally. The US market is seen as the most promising one. However, as the regulations are harmonised throughout Europe, it is regarded as the easiest market.

No matter what strategy or specific sub-industry a company uses to anchor its business, a clear understanding of the market logic and expectations is stated in the data to be the cornerstone of business competence. Constant monitoring of the markets and testing the ideas along the way helps to elaborate the business concept. The process also includes acquiring the patent rights in the area.

3.4.2 Short-Term Weaknesses

Human capital

Even though scientific competencies were seen as an important strength, there are also critical comments targeted at them. First of all, there is a lack of sufficiently competent people. Furthermore, some of the interviewees see that schools focus too much on chemistry and include too little of the other natural sciences.

> *I find that education lacks the sense of …er …the students don't have the mathematics background so even the students coming into the department where I teach, they haven't taken any mathematics, they don't have any physics, they don't have … er …they have a lot of chemistry, but it's not the kind they should learn and so that's one of the areas.*

It is argued that this lack of background knowledge can be one reason for the poor level of method development in Finland. The trend is more that Finnish researchers go to the United States for a time and learn new technologies that were unknown in Finland earlier. At the same time the state-of-the-art methods have been developed further and the technologies brought back to Finland are thus already obsolete. It is not about being expert in a certain technology, but instead one should be familiar with a variety of different techniques, as well as be able to link all of them to a large-scale trial within the specific experiment.

> *I don't know any wet-laboratory method that was developed by Finns. They are all from the best universities in the States. And then this Finnish researcher spends some time there and copies this method and returns home a hero (…) and after four years returns with this old method. (…)But this scholarship though sufficient for learning one trick is far from enough (…) there are dozens of different techniques. They all should be undertaken in a large scale for this particular experiment.*

It is a common argument in the data that research-originating companies often lack business competencies. This leads to a situation where the company tends to focus on research and development, but not on commercialisation and financing. The interviewees feel that there is a strong need for managers with industrial experience. The international venture capitalists are thought to expect solid market knowledge and clear product segmentation. It seems that the key issue for attracting foreign venture capital is the ability to sell the concept to the intended partner. All the development activities should be tied to solving a particular problem originating from the market, instead of developing a research-oriented innovation and then looking for markets, where it could be sold. Besides marketing, the lack of management experience can also result in poor personnel and project management. These include issues like personnel policy, scheduling, budgeting, licensing and other juridical expertise.

> *(…) one of the problems with the biotechnology companies is that in many cases these university groups have undertaken a research project. Then the project is completed in such a way that Tekes claims it has to be transformed into an enterprise project. Well, then they carry on with what they have done in the university, found this "so-called company" and receive funding because they didn't have any other ideas. They have continued to study the same thing without thinking about the market potential of the research or product at all.*

In some cases the managers of the biotechnology start-ups are unwilling to listen to advice from people that already have experience of commercialisation. The ability to listen to such advice could result in considerable time-saving in product development as good use could be made of the experiences of unworkable solutions. Other phenomena comprise unreasonable consultancy and reward expectations of the original innovator.

Structural capital

According to the critical interviewees, the few resources that Finnish research institutes have result in an inadequate infrastructure for making sig-

nificant findings. It is stated that the academic goal of being published can be reached with even less equipment, but being published is far from sufficient for finding a cure for an illness: when an article is written, it is seen as only a beginning. The problem of solving an allergy or illness is so complex that there is no chance of undertaking it without significant additional resources, such as a suitable software platform.

> *(…) this nation hasn't got any vision at all about what should be done. The whole thing is this kind of a laissez-faire, let's try this now - scratch a bit in this corner. Everything fails because this requires such heavy system level research environments.*

On the other hand, legislation restricts the use of the massive databases that Finland has.

> *We would be able to get the kind of data that is very difficult to find anywhere in the world. However, there are these privacy protection matters that are a central problem. And it would be necessary to find common rules on how to operate so that data protection is taken into account. There is no need to find out anyone's identity…*

Relational capital

The funding system of the biotechnology industry is strongly criticised in the data because it is seen to provide only minimal financing. The funding focuses on research and development phases, whereas the needs of the more business and production oriented activities are given a lot less attention. It is argued that this is true especially for Tekes. The system creates various new companies in Finland, but they are too small and their financing structure cannot be based on income funding for several years because of long-term product development. These companies compete with each other, and eventual synergies are neglected. Moreover, the funding system is a serious problem for companies trying to proceed from the early steps but still far from commercialising their products. The foreign venture capitalists are considered reluctant to invest in companies that are in this "valley of death".

There is thought to be a considerable disparity between the directionless approach of public funding on this level and the investments at the earlier business levels. It is difficult to get even the most promising ideas developed to a stage at which they would have commercial relevance, like phase three in drug development. Additionally, the problems in financing have compound effects as contract research organisations also lose their customers. It is further argued that expanding companies

have difficulty finding skilled advisors that would be able to consult with them in the internationalisation phase.

> *In other countries they invest a lot in internationalisation and the growth of the company. Here the funding stops at this point. (…) Technology or product candidates and the whole commercialisation process are the responsibility of the company. And yet, the need for funding is greatest in the commercialisation and internationalisation phase, and then this funding ends. And then we all are surprised that the companies do not survive.*

At the same time, even though basic research is argued to constitute a solid foundation for the Finnish biotechnology industry, there is also a lot of criticism about its scarce funding. The wages are poor in graduate schools and it is difficult to find funding for sufficient equipment, like mass spectrometers. On the other hand, the terms of academic funding usually require publication of the results, which can be contradictory to the aims of patenting an innovation.

The weaknesses of the funding system force academic research groups to set up a company at a too early stage. The other alternative is that a research group enters into an alliance with a company, but this alternative is seen as tying up the intellectual property rights that are created in the process. On the other hand, job rotation between companies and academia is seen to be difficult because wages are so much lower in the academic environment. Thus, short visits to the business world can easily turn into permanent employment. It is argued that the situation is better also in this respect in the United States, where academic work is well paid.

Some interviewees see that the financiers' expectations have been based on unrealistic assumptions because of insufficient professional competence to evaluate the chances of the project being successful. This has resulted in very ambitious business plans; there are several Finnish pharmaceutical companies that could enter global markets with original compounds. However, a typical investor-dictated period of, say, five years is far from enough to create a prosperous company having the resources necessary for a global market launch. Furthermore, it is presumed that drug development companies can make it to phase 2 or 3 at best, but production is quite unlikely to take place in Finland. Instead of facing the facts, financing is based on hype, according to which flourishing companies can be created in a few years time and their role in securing the Finnish national economy is said to be considerable. It is even argued in the data that funding organisations actually expect an exaggerated success because realistic descriptions result in negative funding decisions.

> *(…) the amount of money coming in for investments is too small. I think the estimate of how much time it requires to develop a product, er… people are underestimating it.*

Some interviewees see that it is better to try to cope without venture capitalists' involvement as long as they are not sufficiently in tune with the needs of biotechnology companies. The national financial markets are so small that there is practically no competition. Thus, the few venture capitalists can dictate the terms of funding to a considerable degree and are able to wrestle significant decision making power from the founders in managing the business.

The attitudes of the general public weaken the business opportunities of the biotechnology companies. It is a common reaction that biotechnological solutions raise disagreement among consumers, because they are thought to be mysterious and, thus, fall often prey to suspicious rejection. For instance, in the environmental sector smart microbiology is based on bacteria, which often invokes negative imagery. It is difficult to enter orthodox markets with a new kind of solution. Another every-day example is the food industry where people are looking for novelties while being very conservative in terms of safety, purity and naturalness of products at the same time. On the other hand, regulations make it difficult to market the health effects of food. According to the interviewees, the requirements that the pharmaceutical industry must adhere to are unsuited to the food industry, because it is more difficult for the latter to prove the efficacy of their products than it is for the former. As the food industry is not allowed to use claims without scientific evidence in their marketing, it has to rely on positive mental images as well as the use other consumer marketing efforts.

Value creation

Even though it was stated in the strengths that Finland is a good test market, the small size of the country also has its downside. The Finnish home market is too small in proportion to the research and development costs that are unavoidable in this industry. This forces companies to base their business strategy on broader international markets. The pressure of internationalisation increases the difficulties in business operations.

> *Finland itself is a small market. Therefore all these development activities should be targeted at the broader market area…that is international markets.*

3.4.3 Long-Term Opportunities

Human capital

The role of training is seen as central to enhancing the future commercialisation of biotechnology innovations. It is stated in the data that the American education system would provide a good baseline for developing Finnish learning requirements. Some of the interviewees argue that business schools would be a good source for more business-oriented managers in the field, whereas others believe the researchers should be educated to better understand the management and business issues. On the other hand, Finnish researchers are well-informed about commercialisation opportunities, compared to their American colleagues, for example. Specific programmes could be implemented to help young professionals gain experience of international markets.

The interviewees emphasise the importance of hands-on experience of commercialisation even more than training. Working abroad improves the opportunities for entering more demanding jobs. Such a development opportunity would be an important asset for the future of the Finnish biotechnology industry because expertise should develop quite rapidly.

As it was stated in the section on strengths, managers with industrial experience are an important asset for companies in this field. Their competencies also form a considerable potential if their know-how could be disseminated more widely across the companies. Many big international drug companies that are established in Finland have Finns in key positions. It is also possible to look for experienced management in other industries and abroad. There are people who have, for example, been working in the information technology sector and, thereby, gained experience in international business. They could bring their own expertise to the biotechnology sector that is then complemented with the scientific competencies of biotechnology experts. It is argued in the data that such combinations could form very effective sales groups.

> *(…) that there is a need for professional business administration that has industrial experience. Like in our company, our CEO is a former financial director of this big Finnish industrial enterprise. He has strong international expertise in finance. And I have some thirty years of experience in the pharmaceutical industry including also positions on boards of directors. Our research director has been six years in the United States.*

Structural capital

The Finnish patient register data would be very valuable if it could be subordinated to drug development. However, its potential has been practically neglected so far. According to the interviews, it would be a huge opportunity for Finland to set up an institute that would screen the data with mathematical and statistical methods. These findings would then be linked to what is already known about specific diseases and the role of genes in their pathogenesis. This requires a major investment of several years, but could potentially render significant results with regard to diagnostics or therapies of diseases. However, such an approach would require changes in the legislation that in the current situation prohibit the use of the data to commercial purposes in order to protect the individual's right to privacy.

> *And the health care system has produced a lot of information that could be commercially exploited even internationally. And therefore I would hope that all this information available could be accessed better and upgraded further so that these commercialisation opportunities would be exploited better than they have been. (…) companies are not necessarily primarily interested in who are the individuals in the data. The information as a statistical mass is already so good and huge that if we could use it, it could be developed into the kind of products we are trying to develop here.*

Besides the opportunities of the Finnish register data, another field that could have a potential is combining different fields of expertise to expand the range of applications to new industrial sectors. A new kind of collaboration with instrument manufacturers and the information technology industry would bring an engineering science approach that could open many new doors, e.g., in software development, measurement technologies and automatic control engineering.

> *R1: [Finland would have a particular advantage] on the silicon side, yes.*
>
> *R2: [Finland has absolutely an advantage] in this whole information and engineering technology. (…) these really big boys from MIT and Harvard still think that these various length units of DNA, proteins and metabolites cannot be put into the same database, that it is impossible (…) But we have done it and it really works. We can seamlessly navigate from gene to metabolite and back.*
>
> *R1: But even we are at the very beginning and it should be remembered that I come from the ICT sector. In the beginning we made this huge network control system and it was then state-of-the-art. Now for three years we have developed this software further and an elementary version has been completed. I think that this gives you some kind of understanding about the complexity of this approach.*

Relational capital

It is argued in the data that networking is almost a prerequisite for small start-ups in the biotechnology sector. The role of large Finnish or Finnish-based companies, like Orion, Alko-Altia, Cultor-Danisco and Valio, is crucial in this relationship. The smaller companies are able to come up with innovations, but it is usually the established companies that have enough resources to complete the commercialisation phase. In order to enhance the networking within the industry, it has been suggested that funding institutes should take a more active role in building connections between companies, as well as other institutions and authorities. Various governing bodies, like the state-owned financing company Finnvera, Finnish Industry Investment Ltd and National Agency for Medicines, could be linked to the technology programmes of Tekes with their goals being aligned. This alignment would help create a system that comprehensively supports the companies' aim of commercialising their innovations.

> *(…) in the beginning there would be Employment and Economic Development Centres. Tekes would be there in the beginning, too, as well as financing various research and other projects. Then Sitra or some other similar institution would come along and get this company established in the markets. And Sitra should also provide links to these bigger international investors that would bring increased funding and bigger markets in the later phase. So this would form a pipeline that would take the companies to the global markets.*

On the other hand, the interviewees see that funding institutes should focus their support on fewer but more long-term projects. Advancing the projects could be measured by milestones that trigger the funding up to the next milestone. If these intermediate goals are not met, the venture capitalist can decide on the future actions, but if the project proceeds according to plan the continued funding is also secured.

The managers of the successful medium-sized and large biotechnology companies could be a suitable pool for recruiting expertise to the boards that would define these contract terms. The reorganisation would solve financing problems that companies face in the commercialisation phase. Longer term funding would also cover the costs of marketing and intellectual property rights instead of just research and development. If the follow up evaluation is not organised, the grounds for public sector support are not clear.

> *I think many people agree that scarce money should be focused a bit more, especially when the commercialisation phase begins. Companies in that phase should be sorted out so that those which shape up should be supported more.*

> *And find out the opportunities for building bigger units all together and support those. There is not enough money for everyone.*

Besides creating explicit grounds for funding, the data suggests that the public sector institutes should also take a more active role in developing the national strategy for biotechnology. This entails defining focal areas within the industry, the results of which could then be utilized to direct the allocation of funding in order to create a new Finnish industry. Otherwise it is probable that Finland remains a country where small companies develop the early phases of technologies and then sell them and start the development anew. This approach is unlikely to result in new industries. It is argued that the funding institutions have a central role in starting such development but the companies should also participate actively in defining the areas of strength. Historical references to areas, in which success has been achieved, are seen to be an important aspect in this respect. Naturally, the evaluation of the current operational environment is another source of information for outlining activities.

> *It really is so that money talks. It is not possible without the contribution of the funding institutes. Tekes has done a good job with these programmes in which academic groups have been forced to collaborate. Some similar activities are needed here in business, as well. And this comes through financing.*

It is argued that such a strategic focus would help to create structures, which would guide the development in a certain direction. Moreover, the strategic focus could be used for creating growth engine companies that smaller companies could link up to. The key issue is that Finland should be able to create larger entities that can eventually attract the interest of international investors, as well. To sum up, all the Finnish companies should be seen as elements of one single bio-cluster instead of various ones in different regions. This unavoidably means that the number of companies would have to be reduced and become consolidated. On the other hand, the strategy of focusing support is also criticised in the data in that this can leave good initiatives unfunded.

> *One opportunity that Finland could have is that because we are a small country this calls for a certain level of cluster building and collaboration between different sectors. If we could do this and develop it further, it would be an opportunity that would create a whole lot more innovativeness.*

However, the national activities are not sufficient; the interviewees see that the whole industry should also focus more on the international context. The financial base is too small to create world-wide success stories, for ex-

ample in drug development, because clinical research with patients is so expensive. Therefore, companies should have more courage to seek international partners that are able to help in the early phases of internationalisation. It may be the case for many companies that the leverage of networking at the European level is not enough. They really have to look for global opportunities across continents as well as industrial boundaries. On the other hand, international collaboration also makes it possible to recruit highly experienced experts for both the public sector support institutions, venture organisations and the companies in this field.

> *Competent management is always available but on normal terms. People can certainly be attracted here from the USA, but they must have sufficient authority to act. And this means that the structures must be clear and the governance explicit. If I as a venture capitalist was asked to manage a state-owned venture capital organisation, I think it would be a dream position: to see and to make decisions more far-reaching than is possible in this purely market-driven world.*

In the data, there is a strong demand for a large fund that would also attract foreign investors. This fund would distribute the risk among Finnish companies, and shares in this fund would also be sold to foreign institutions. These new instruments might alleviate the problems growth companies have with funding. It is argued that such a solution is very much in line with the interests of domestic investors; they can then use their networks to attract foreign investors. In fact, Finnish venture capital organisations have already actively sought international partners.

Evidently not just Finnish companies suffer from the problems related to funding. The interviewees see that a European Nasdaq covering the whole continent would reorganise venture capital opportunities. It is argued that the current underdeveloped financing system prevents the renewal of the industrial structure. Institutional investors do not see exit opportunities in the current financing system, and are therefore reluctant to make investments in this field. A technology-based cross-European stock exchange would be able to provide greater liquidity.

> *[The inefficiency of the capital market] is a European problem in the wider scale, but the situation is still a bit better in Western Europe. There are more of these venture capitalists and risk investors and others and these make the markets somewhat more functional. But the basic problem is that the stock exchange market does not support companies in Europe, in general. And this is the basic problem, which is reflected in the risk investors' behaviour as they don't have an effective exit-market like they have in the United States that has had dozens of public listings even this year and they also include biotechnology companies. So the situation is quite different there.*

Value creation

In the data it is suggested that companies can survive in the tightening competition by specialisation and by developing products that have a higher profit margin. This approach reduces the importance of high sales volume. Besides specialisation companies also have to be able to explain what advantages the product features compared to its competitors.

> *(…) usually, this industry is not about producing a gigantic volume. It is more about products with a high profit margin that are sold in limited amounts, units.*

The logic of the biotechnology industry differs from Nokia, for example, because there is seldomly a strong cash flow that can be used to create new technologies. Drug development, for example, is a high risk and long-term investment because the average development time for a new drug is 13.7 years. The companies are usually highly dependent on public sector funding, but eventual success brings big profits. Furthermore, the lifecycle of the products that reach the markets is also long. This makes the business very stable once it is created.

> *When it comes to these opportunities, the research, business and markets are global and then even small investments that are made in successful ventures produce business where the scale of economics, global economy usually, provides a very high return on investment. This is obvious.*

On the other hand, the service products, and also diagnostics to some degree, can create a cash flow already in the early stage. It is argued in the data that building Finnish high-level expertise into service products could take it to the international markets, because Finnish research is also highly recognised abroad. Some of the interviewees see that the services are actually the key for turning biotechnology into a new field of industry and employing highly educated people. The service companies could be tied into drug development, for example. Some of the successful Finnish companies working in this field actually have their roots in a conventional and highly competitive environment instead of high-technology niches. The product development cycle is much shorter and cheaper also in the diagnostics field, which makes the chances for success better than in drug development.

> *But I think that these small [companies] that focus more on services and sales and thus create profits, I think that some of these will turn out to be success stories.*

Besides health care related areas, the data show that environmental techniques can also be expected to create effective and innovative solutions. Waste-water, polluted soil, composting techniques for waste management and other environment applications are expected to be increasingly dependent on biotechnology. Even though the general public shuns the possibility of biotechnology solutions in the environmental sector, there are already some pioneering industrial clients for these markets.

> *Yes, I see, absolutely [a considerable market potential in the environmental sector]. (…) legislation related to the environment is a challenge, and companies in the traditional chemical industry aim at using more biotechnological solutions that would make their production more environmentally-friendly.*

The data raises the question of how the success of the biotechnology companies should be measured. According to some interviewees it might be reasonable to argue that spin offs and mergers with foreign companies are a successful outcome as such. On the other hand, the aim of creating a new industry to support the Finnish national economy could require high Finnish ownership. The data also raises the question of where Finland should invest if not in the biotechnology industry.

The interviewees see that the development boom of the late 1990s is largely due to Sitra's early-stage investment policy that made it possible to establish companies. However, the nature of the biotechnology industry is such that it requires a long-term perspective and therefore it is perceived to be important that public funding still is available in the future. Another approach of developing the bio-related industry would be a convergence of the health care and information technology sectors. However, this would not be based on biotechnology research, which has created good grounds for developing a new original field of industry of its own.

The data suggests a specific structural solution to exploiting the genetic material and data governed by the National Public Health Institute. The idea is to found a state-owned company that would sell rights to companies that allow them to utilize the data in their development activities. It is argued that such a strategy does not differ much from the governmental post-war investments in the metal industry and petrochemicals, for example. It is suggested that if a small share of such a company were offered to be sold to private investors, it would create considerable interest even on global scale.

3.4.4 Long-Term Threats

Human capital

About a dozen respondents in the data express concern over the future of the Finnish biotechnology industry and, consequently, about their own business activities. The suspicions are focused especially on drug development and research-based activities. There have been only a few even modest success stories resulting in an international status. This is regarded to undermine the financiers' willingness to invest especially in companies that are in an early stage of commercialisation.

The problems related to commercialisation may partly arise from the insight into how the business activities are created in this field. Because it is so technology oriented, there is an illusion to some degree that commercialisation would be a trivial issue. Other interviewees see that business competencies have to be implemented in a company from the very beginning. Failure to organise management and marketing functions is recognised as the biggest threat by some interviewees.

> *It is necessary that certain research serves to create knowledge. Applications will emerge unavoidably, when we know what we need.*
>
> *[Business competencies] are never created unless they are forced to do it right from the start. It should be started so that the core people are forced to do fundamental business-related work from day one. And then, after the project, they should be evaluated to see if they have been able to come up with both the required material and have undertaken these management activities so that it would be a viable company in general. Certainly, external help and consultants can be used, but the main managerial training should be acquired through doing it yourself.*

Decreasing opportunities to recruit competent experts is another threat related to human capital. As to managerial competencies, this threat is related to ageing. Managers with industrial experience in the field are very often over fifty years of age, and the retirement rate will be high during the next decade. On the other hand, there are also implications in the data that the education system is not able to meet all the requirements of the industry. At the same time, it can be difficult to attract experts from abroad, because the image of Finland as a modern high-tech country is still somewhat blurred. The bureaucracy relating to foreign employees is also mentioned in the data. The threat of lacking competent personnel can become even more serious in the future because company growth will clash with a scarce la-

bour force. In future, the availability of experts may be a bigger problem than funding.

> *I think education has been one of the big problems, because I think for biotechnology it really is the individuals and their training and experience that makes them valuable. And it is difficult to get training. Almost everyone in our company now has somewhere between eight and twenty years of experience, and it is very much, it requires a lot of work to solve the problems. And they are good at it. But in order to expand we need more people. (…) So we are already running out of talent. We have, I think, all the key players in Finland working for us.*

Structural capital

We were not able to identify any statements of structural capital that could be classified as a long-term threat.

Relational capital

The future of funding is one of the most pertinent threats for the biotechnology industry. The interviewees see increasing suspicions among the venture capitalists. This reduces the funding allocated to the industry. At the same time, declining domestic interest also weakens the international institutions' willingness to invest in Finnish companies. The competition within the biotechnology industry is expected to tighten even more in the future. It is obvious that companies that are too small cannot overcome the challenges related to the development of high value-added products. This is expected to affect the funding opportunities and also increase consolidation of the companies. These changes in the market structure will also be reflected in the labour markets through increasing uncertainty.

> *The biggest threat is continued funding. And it can lead to a situation where smaller companies have to merge and ruthlessly screen out the best product ideas that are then developed further.*

The companies in commercialisation and growth stages most dramatically illustrate the funding difficulties. According to the interviews, financing for research and development activities is quite readily available but additional funding is difficult to find. Even if venture capital were available, the contractual terms are often regarded as unreasonable because companies risk losing control of their innovation. When companies have products on the markets and constant turnover, it is again easier to find both domestic and

international private venture capital. Therefore, the role of public sector venture capital is seen as essential especially for growth companies. The public sector institutes are regarded as the key for developing biotechnology into a remarkable new industry in Finland.

> *Currently the lack of capital is troubling these development companies and it would be necessary for public sector institutes to be patient and believe in this concept. This is because these private investors, which are relatively few, follow the decisions that Sitra and others make. And these trends that the public sector institutes set reflect on the private sector. So the threat is this declining belief, and the consecutive cessation of development inputs from these public venture capitalists.*

The interviewees commented strongly on Sitra's plans to withdraw from funding the biotechnology sector. As it was stated above, the role of Finnish public institutions is considerable in funding the biotechnology sector. The future of Sitra's funding creates uncertainty among the interviewees because it has been a pioneering venture capitalist so far. Sitra has actively funded companies in the intermediate phase, when they have research and development projects up and running but no products ready to be launched on the markets yet. The interviewees see that a state-owned venture capital organisation is even expected to take a higher risk than the private sector. According to the interviewees, the companies that Sitra has invested in are gradually getting into the commercialisation phase and therefore it is seen as a mistake to withdraw their investments now. If Sitra does abandon the biotechnology industry, it is essential that the portfolio is sold instead of just closing it down. On the other hand, Sitra's investments are also questioned. According to some interviewees American investors see a state-owned funding partner as a problem.

> *Sitra's activities are now characterised with some uncertainty about what will Sitra's future role be in this field. And our worry is that this will end the funding of start-up biotechnology companies. Venture capitalists are already funding and focus even more on companies that have already advanced in their business activities, and Tekes and the Academy of Finland, on the other hand, focus on R&D and very early business activities – even projects that precede starting a company. This creates an enormous gap in the funding structure of the start-ups. Sitra has filled this gap so far. But these new decisions are somewhat threatening to us.*

The data is also critical of the fact that the investments of the domestic venture capital business are channelled abroad resulting in both lost jobs and expertise. Funding problems lead to a situation where the development of the European biotechnology industry lags behind the

United States. European universities suffer from insufficient resources, and companies have to focus more on business models based on their own turnover. This development is said to slow down the growth of the industry because short-term turnover is often created at the cost of long-term growth. At the same time, American companies and universities are able to get sufficient financing. Finnish expertise falls by the wayside because of the lack of funding. Additionally, the better functioning operational environment also attracts the most talented researchers abroad.

> *I think that the threat is that we can't keep up this drive required to develop this industry further, and especially to have new companies founded constantly. I know that there are various opinions here. I do find it important that current companies are developed but if we want to maintain the dynamics of this industry, it requires that new things are created here constantly.*

The interviewees see that regulation should be modified in order to get international investors interested in Finnish biotechnology companies. Drug development is a high-risk business that requires a long-term investment policy. Therefore, the lack of venture capital clouds the future especially for these companies. It is argued that drug development is in a transitional period that sorts out those companies able to develop drugs with a sufficiently high market value to secure the future of the company. However, even if they succeed, the revenues are still seen to be relatively small.

> *(…) even though they were in the phase that they are making different licensing agreements and selling their technologies – if and when one out of hundred medication ideas is successful – the profit still doesn't come to Finland. At most it is royalty and licensing income. (…) this huge investment that we have in different drug development companies – you can see that it will require a huge amount of money and the cash-flow back will be relatively small, compared to these investments.*

The lack of a clearly defined national strategy for biotechnology raises the prospect that funding will be directed to the latest hype areas. This makes it more difficult to create the necessary industrial infrastructure as there is no hype in that. However, successful pioneers can only be built on a sufficiently strong technological base. Additionally, competition is also extremely tough in hyped areas.

> *I would balk at the common idea that after some fashion research emerges in the USA the European Union also decides to focus all research in this area, and then the interest in Finland also increases. As a Finn I would be keen to avoid these fashion trends because they are highly competitive areas.*

Collaboration between companies and universities should be clarified. The increasing demand of market-driven research projects challenges the traditional academic research approach and aggravates the relationships between commercial and academic research institutes. It is common that academic research presents publicly unfinished results as an opening into new areas, whereas the business world keeps quiet about its intentions and comes out with completed projects protected by patents. It is also argued in the data that companies are in the best position to observe the market needs. On the other hand, the lack of venture capital results in sub-optimal exploitation of the potential in academic inventions. And finally, the increasing service activities of universities are a direct competitor to the private service companies. Increasing demands for self-financing of the universities force them to provide service functions to secure their operational preconditions.

Even though international collaboration opens many opportunities for the industry, it also brings many risks with it. Finding reliable collaboration partners can be challenging, and differences in cultural backgrounds can also create misunderstandings. It is impossible to even plan a deeper collaboration without meeting the candidates in person. Furthermore, international collaboration also raises difficult questions about ownership and the distribution of profits.

> *(…) it is wise to think about the whole world as the market, so that entering that scale is an extremely slow and difficult task. Therefore it is important to create partnerships sufficiently early with such organisations that can act efficiently in the commercialisation phase. This is one remedy, yes. But then are these ownership issues and all, which are very difficult, as well. It is easy to say that yes this is necessary but then in practice the negotiations about the ownership structure, when we enter these issues, they are really difficult.*

Value creation

According to the interviewees the difficulties in financing may lead to a situation where the returns of the considerable investments by the Finnish public sector will be funnelled abroad. According to the data it is a key issue for the Finnish biotechnology industry that companies would have a sustainable Finnish ownership. It is noted that state-ownership would be one way to ensure that companies are not sold at an early stage to foreign investors. Insufficient financing leads to a situation where the product is ready but the company does not have money to commercialise it. The company is forced to sell the rights relatively cheaply, and it is the foreign investor that reaps the benefits from the original investment. On the other hand, produc-

tion activities are much easier to locate in the countries with financial and commercial hubs.

> *(…) numerous small companies are founded on Tekes money. And if some of them survive to the phase like ours is, then a venture capitalist buys it relatively cheaply. It is developed a bit further and then it is sold to a foreign buyer, Americans, and it is merged into some foreign organisation. It disappears from here. I mean they cash in on the investment that the Finnish state has put in these. And I see that it doesn't create any jobs here.*

3.5 Conclusions

Short term aspects

Biotechnology leaders have great confidence in the scientific competence of the actors in the Finnish biotechnology industry. The companies are exceptionally satisfied with the overall public sector support. The latter finding bears striking similarity with results from the Flash Eurobarometer: Finnish entrepreneurs show a strong reliance on the help and advice from public sector officials instead of private sector experts such as lawyers, auditors and private consultants (Hyytinen and Pajarinen 2005). The findings suggest that the support provided by the public sector is tailored to meet the needs and wants of the biotechnology entrepreneurs, and that in the biotechnology sector this enables a continuous focus on scientific competence.

Tekes and Sitra are the main governmental financiers, providing together approximately 30% of the total equity and capital loan funding for the Finnish biotechnology industry (see Tables 2.5 – 2.10). Tekes and Sitra have a strong role in the early stage financing, and they seem to collaborate actively in biotechnology financing activities. Paradoxically, Tekes is seen as an unambiguous strength for the Finnish biotechnology industry, whereas the respondents regard Sitra as a clear weakness.

Moreover, the biotechnology sector leaders identify an urgent need for additional financing, expressing it as a major weakness of the financing system. However, as the financing market in Europe is usually regarded to be relatively well developed, it can be argued that financing should be available for feasible investment opportunities; and if so, this raises the question why money is not attracted to the Finnish biotechnology industry.

A common denominator for these apparent discrepancies could lie in the second strongest weakness disclosed by approximately 50 percent of the interviewees: lack of business competence. It is possible that the companies can, due to a lack in business competencies, have difficulties in assessing

possible shortages in their value creation mechanisms. On the other hand, the companies highly appreciate their scientific competence, which is tightly linked to technology oriented public sector subsidies. Consequently, the companies feel that their technological excellence should already justify the financing of projects. As a result, the lack of private equity financing is interpreted to be caused by a flaw in the financing system itself.

The strong public support of the Finnish biotechnology sector has been a decisive factor in creating a strong scientific knowledge base. The current knowledge base covers a multitude of scientific disciplines and serves as a foundation for developing a broad range of different applications. However, a lack of focus and the resulting development of a plethora of different applications is not necessarily beneficial and far from optimal in terms of strengthening the industry and its competitive advantage on global scale.

As will be implied by the central conclusions of this book, the quartet of (*a*) high scientific competence, (*b*) Tekes, (*c*) a qualified public sector support and (*d*) an exquisite health care infrastructure should bear with it a potential for future success. Our analyses on patenting data (Chapter 4) are in favour of this notion, as are the opinions of the interviewed biotechnology industry leaders presented in this chapter. However, as success still lies in the future, the next few steps are crucial. There is a need for a strategic focus.

Long term aspects

The topic that is spontaneously brought up most frequently by the biotechnology leaders deals with the financing system also in the long term category. Thirty percent see its inadequacy as a threat, whereas twenty percent identify hidden opportunities within a more favourable development. The most significant threat is seen in the behavior of the main – and virtually sole – governmental venture capital institution Sitra[1].

As the overall future prospects are regarded both positive and negative, and as the major opportunities and threats concern the financing system, it seems that a majority of the business leaders in the Finnish

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[1] The survey was performed during fall 2004, a time period when Sitra was refocusing its financing efforts. The issue was discussed also in public, which might have influenced our results due to the survey method (open, unstructured question). However, due to Sitras position on the Finnish venture capital market most of the companies initiate discussions with or about Sitra at some point of their life cycle. Consequently, Sitras' role in the financing of the biotechnology sector has been and still is central, leading to a continuous interest for the behaviour of Sitra.

biotechnology industry identify lack of money as the main obstacle for success. Somewhat surprisingly, professional leadership is identified as an opportunity only by five percent of the respondents. This is to be contrasted with the deep concern for a lack of business competence described as a short term weakness. We also find it confusing that public sector support is mentioned only as an opportunity, despite the apparent growing discrepancy between demand and supply of governmental financial support.

The identified threats associated with Sitra are twofold, arising from a fear of Sitra to diminish its financing activities on the biotechnology sector. This could lead to:

1. A cessation of monetary support
2. A bad signal, as other venture capitalists could interpret Sitra's withdrawal as a sign of bad prospects in the field.

However, some interviewees also see Sitra's presence on the market as a threat because some venture capitalists regard a governmental venture capital institution as a distorting player on a financial market.

Insufficient possibilities for early-stage investors to exit are regarded as a major shortcoming in the Finnish biotechnology sector. A functioning exit-market requires a transparent forum with sufficient competition to enable a constant monitoring of the quality of research as well as the realistic market opportunities for potential products. New investments also require a trade-off between minimizing information asymmetry, on one hand, and maximizing a company's present value in financing negotiations on the other. An efficient management of the trade-off is possible only through a well-developed open financial market including knowledgeable venture capitalists and larger companies in an international context. This is especially critical for a small open economy such as Finland, due to a very limited internal market, limited resources and a high-quality but scattered and scarce scientific knowledge.

Some of the respondents seem to have identified a collection of interdependent factors. The ability to focus, international collaboration and diffusion of benefits, small scale, and networking form a tetrachord that is regarded as important to skilful management. Small scale necessitates finding a niche, and, in turn, operating in a niche area requires an orientation towards global markets. Global marketing requires networking and collaboration with an international enterprise.

Theories of geographical economics support the reasoning between small scale and the need for focusing, which leads to regional specialisation and an enhanced critical mass in relative terms. This issue is discussed in-depth in Chapter 5 based on our findings from the regional specialization and distribution patterns of the Finnish biotechnology sector.

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CHAPTER 4

Biotechnology Patent Citations: Economic Value and Technological Significance

Nikulainen, Tuomo – Hermans, Raine – Kulvik, Martti

4 Biotechnology Patent Citations

4.1 Introduction

Patents form a central pathway for capturing value of the intangible assets in a knowledge-intensive business. Patents can potentially generate and support earnings in two ways: 1) they can be traded or licensed out and 2) they can provide critical protection for core production technologies or products that are to be traded.

In patenting the invention goes through a rigorous and objective verification process as laid down by the regulations. The patenting reduces the level of asymmetric information between inventors and investors and provides collaterals for the company; both are important means of controlling risk. This gives the company an opportunity to obtain financing at reasonable terms.

A patent provides a basis for claiming markets, but not without a trade-off. The patenting procedure itself requires additional resources. A patent can also be challenged by competitors: in high-technology areas, it is rare that new inventions are not patented by other innovators, and hence opposition to patents is relatively common. Furthermore, with the patenting procedure a company discloses its intellectual property, but it does not necessarily possess sufficient resources to protect its patent(s) from consecutive larger competitors' infringements due to high costs, such as legal costs.

This chapter provides an insight into the technological significance and economic value of biotechnology patents in two ways (Figure 4.1). First, we quantitatively analyse the patenting activities of the Finnish biotechnology industry. Second, we assess the quality of the patenting activities over the past few decades by the use of citation indices. We focus especially on the basicness and appropriability of the company patent portfolios and relate the biotechnology industry to other comparable Finnish industry segments. As the present value of science-based start-ups should be able to be linked to the commercial applicability of its patent portfolio, our aim is to provide an alternative approach to the valuation of the Finnish biotechnology industry.

This chapter is organized as follows. This first section briefly presents the general characteristics of patenting. The following section gives an analytical review of the literature concerning the use of patent statistics. Earlier research on patenting in the Finnish biotechnology sector is summarised in

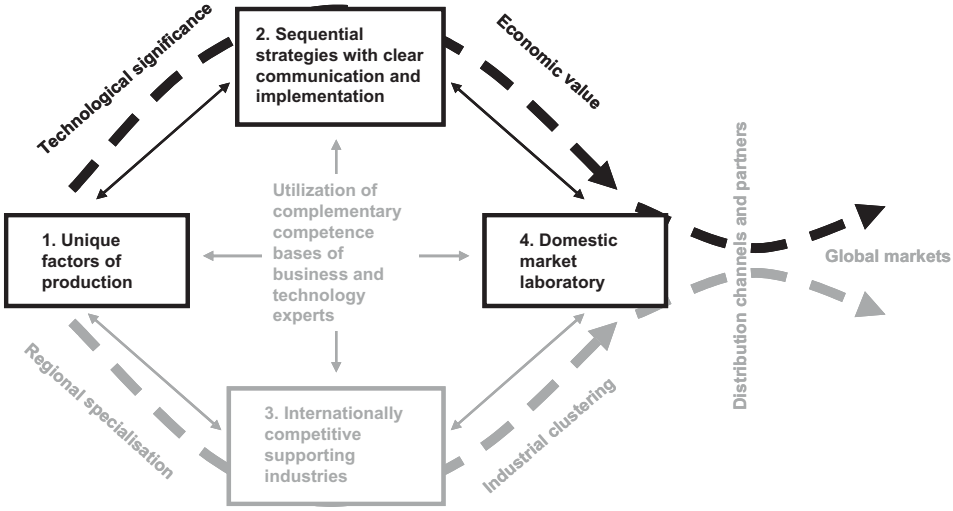

Figure 4.1 Technological significance and economic value of patents in sustainable technology development

section three, followed by a presentation of our new material and the methods we used for analysing the data. The results are presented and interpreted in section five, and finally we conclude this chapter with a brief discussion of the results, as well as suggestions for future research.

4.2 Analytical Background

In this section we discuss the patent characteristics, the advantages and disadvantages of using patent data, and finally we present some indicators for economic research that we have found to be most relevant for our analysis – most notably the patent citations.

4.2.1 Patenting Policy

Patents can be licensed out and used in cross-licensing agreements. Therefore we can say that patents are used not only to protect intellectual capital, but they also function as a tradable commodity. Throughout this chapter we refer to patenting activities as innovative activities.

For a proper use of patents in economic analysis we must define the terms invention and innovation. An invention is typically defined as a new idea, while an innovation is defined as a commercialised invention. This definition goes back to the seminal writings of Schumpeter (1911/1968).

However, the border between these two definitions is often blurred. Sometimes a pure invention – even a patent – might have great economic value without direct commercialisation, and a patent can build on several inventions.

Patents are recognised among economic researchers as an intermediate indicator of innovation activity. Although there are other legal means to protect intellectual property, such as copyright and trademarks, patents are the most common, and they are also the ones to provide actual documented information about the protected property. Patents disclose very much information concerning the actual invention, related inventors, firms and other parties involved and, most notably with respect to our study, the references to related patents.

The patent system aims to facilitate the appropriability of inventions. Appropriability is defined as the ability of inventors to capture financial and other benefits stemming from their inventions. A patent provides exclusive rights over an invention for a maximum of 20 years, however with some variation between countries. The owner of the patent must annually pay an increasing renewal fee in order to uphold the patent.

In case of illegal reproduction or other infringing activities, it is the patent owner's responsibility to take action. No other party can enforce the patent rights, and disputes are settled in a court of law.

A patent grants exclusive rights for the inventor, while at the same time compensates society through disclosure of the invention in the patent application. This disclosure provides a basis for rapid technological development, new inventions and technology diffusion.

A patent can be granted for an invention that is novel and nontrivial, and which potentially has commercial applications. All inventions are not granted patents, due to any of the following reasons:

1. The invention does not meet the novelty criteria set by governing patent offices. The inventor might be unaware of this since he or she does not have a complete insight into the patent pool, and consequently the invention or something very close to it might have already been patented.
2. The invention might be considered trivial. Persons working in the same field can find the invention to be something already in common use or too trivial to be patentable.
3. The invention is not reproducible in a commercial sense. The invention must have a stated commercial application: it has to be a technical solution to a specific problem.

Inventions are categorised into process and product inventions. Process inventions often rely on non-patent methods of protecting intellectual property rights, such as secrecy or tacit knowledge. For product inventions the use of these strategic/non-patent options is much more difficult; as the product enters the market, it becomes vulnerable to reverse engineering, for example.

Cohen, Nelson and Walsh (2000) found that distinct industries rely on a variety of mechanisms to protect their intellectual property. They show that patenting is very common in the chemical and pharmaceutical industry. This preponderance to patent stems from the fact that research and development projects related to drugs and chemicals are often relatively large investments, which is why companies prefer the juridical protection of their investments. We assume that the same logic applies to the biotechnology environment.

For an infant knowledge-intensive company, patenting provides an essential form of structural capital. A patent verifies that the company possesses critical knowledge and, just as importantly, that the company is capable of converting the tacit knowledge of innovators into reproducible codified knowledge. An appropriate patenting procedure signals technological feasibility and serves as an externally acknowledged form of intangible assets. The intangible assets, in turn, generate expectations of positive cash flows in the future. Consequently, the resources are typically steered towards applying for patents, crucial for obtaining further financing. From a venture capitalist's point of view, patents signify the innovativeness and future profitability of a company.

A relevant aspect in patenting is also the timing of patenting activities. Patents are applied in the early stages of inventive activities, typically as soon as they have met the criteria of patentability. Hall, Griliches and Hausman (1986) showed in an empirical analysis that R&D investments and application of patents happen with very short time lags. This indicates that these investments are protected as early as possible.

In the following we will focus on ways to measure the economic value and technological significance of patents. A more detailed discussion of the patenting process, the patent characteristics, the advantages and disadvantages of using patent data in economic research and the different application areas in economic analysis can be found in Nikulainen, Pajarinen and Palmberg (2005).

4.2.2 Patents as Indicators of Added Value

We approach the valuation of patents by using patent citations collected from the actual patent publication. The citations in the actual patent docu-

ment are indications of prior art, the existing body of knowledge. These citations are made by the applicant and verified, and possibly amended, by the patent examiner. The role of these citations is to limit the scope of protection and indicate which inventions are related to the patented invention. Backward citations position the new invention technologically with respect to previous patents (Figure 4.2). Citations by other patents (forward citations) are considered to reflect both basicness and the applicability or "appropriability" of a patent, that is, the ability of the inventors to benefit from their inventions (Narin 1993, Trajtenberg, Henderson and Jaffe 1997).

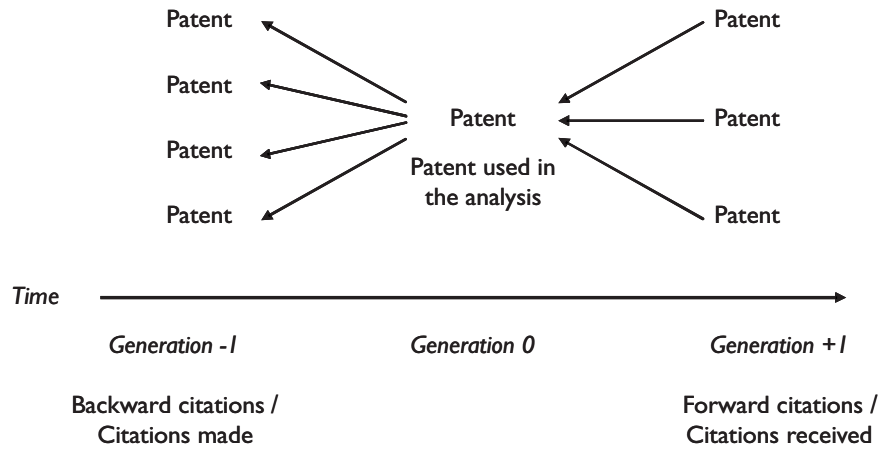

Figure 4.2 Patent citations

The earliest analyses connecting patents and industry value added date back to the early 1960s (Griliches and Schmookler 1963). In the late 1970s the econometric research using patent data was spurred by the availability of U.S. patent office information in machine readable form, and further in the late 1980s as patent citation information in computerised form began to be available. At present vast patent data banks are open for public research, directly accessible through the Internet.

The validity of using patent citations in economic research has been studied several times over the years. This research can be divided into two categories: studies that focus on the validation of the patent related indicators of innovation, including patent citations, and studies that use patent citations as an indicator of economic value and technological significance. The publications by Lanjouw (1999) and Reitzig (2004) are examples of these validation studies. In both papers they use multiple patent related indicators (citations, claims, opposition, family size, etc.) and compare the differences in

estimation results. They find that each indicator has advantages and disadvantages in estimations.

A study of U.S. pharmaceutical patents (Narin, Noma and Perry 1987) is one of the first attempts to connect patent citations to financial characteristics of the companies: by using patent statistics some of the company specific financial characteristics can be explained. Trajtenberg argued that the value of a patent can be assessed from information provided in the actual patent document, which reviews the prior art[1] patents, as well as relevant other sources of reference (Trajtenberg 1990). The protection of the patent is limited to a specific invention and niche as all other related inventions are presented through the references.

Patent citations are commonly used in estimations as independent variables. That is to say patent citations are used to explain, for example, economic performance variables. Such studies include estimations of the market value of firms (Hall, Jaffe and Trajtenberg 2005) and consumer welfare (Trajtenberg 1990). Hall, Jaffe and Trajtenberg (2005) use patent citation weighted patent counts to estimate the market value of U.S. companies listed on the stock exchange. They find that by using patent citations it is possible to receive a more accurate picture of the companies' intangible assets. Trajtenberg (1990) takes another approach and uses patent citations to measure the social welfare effects of inventions. He focuses especially on the consumer welfare side and argues that this is connected to the value of a patent.

Citations to previous patents position the new invention within its application area and are linked especially to the "basicness" of a patent (Trajtenberg, Henderson and Jaffe 1997). The term basicness refers to such fundamental features as closeness to science and originality, closely connected to choices and efforts of R&D. Backward citations have also been used as a predictor of a patent's technological significance and thus economic value (Harhoff, Scherer and Vopel 2003, Lanjouw and Schankerman 2001, Lanjouw 1999, Carpenter, Narin and Woolf 1980).

However, the connection is vague and it shows some ambiguity. Smaller companies might have problems catching the potential of a wide application area, whereas large enterprises can more easily reap the benefits of an invention with several potential applications (Trajtenberg, Henderson and Jaffe 1997, Hall, Jaffe and Trajtenberg 2005).

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[1] The existing body of technological information against which an invention is judged to determine if it is novel and can thus be patented.

If companies within a certain technology field or a complementary application area recognise the technological significance or economic potential of a patent, they may cite it implying a further development of the invention (Albert *et al.* 1991). Albert *et al.* conducted a survey among inventors to verify the existence of this link between citations, and studied how the inventors evaluated inventions and how this is connected to the number of forward citations. They found there is a connection between the number of forward citations and the technological significance of inventions (based on inventor surveys). Trajtenberg (1990) uses forward patent citations to estimate the consumer welfare effects of the invention. He used patent citations in an analysis to a connection between the number of citations and consumer welfare related to CT (computerised tomography) scanners. Harhoff *et al*. (1999) also use forward citations in order to estimate the economic potential of inventions in their study of European patents. The value potential captured seems to be enhanced in settings where the forward citations are made by the inventor herself (self-citation) (Hall, Jaffe and Trajtenberg 2005).

The downside of using forward citations in evaluating the technological significance and the economic value is that they are not available until a substantial time after granting. Unlike forward citations, backward citations do not reflect a realised interest for the technology; they merely look to the past. Consequently, backward citations show more noisiness in estimations compared to other estimators (e.g. forward citations), but using them in economic analysis has also some strong advantages: backward citations are available early in the life-time of the patent (after the publication) and they are available easily through online services. Especially in new technologies, such as biotechnology, the above-mentioned time dimension is very crucial as the forward citations accumulate only over time. The backward citations provide comparable information upon publication of the patent document; consequently, they provide comprehensive results earlier.

In all cases it is important to acknowledge that citations are only indicators. They provide values that are intercomparable, but observed individually the number of citations provides us with only a suggestion of the actual value.

In the next section we present the patent data collected for this study and take a look at the descriptive statistics of biotechnology patenting by Finnish firms. The figures are then compared to other technological areas. Finally we conclude with a company level discussion comparing the economic value and technological importance of patents with company specific data.

4.3 Patenting in the Finnish Biotechnology Industry

A survey conducted in 2004 among Finnish biotechnology firms collected information about their patenting activities.[2] Table 4.1 presents some general results of the survey regarding the patent counts. The survey identifies the difference between large firms and small and medium enterprises (SMEs) and focuses on granted patents and patent applications. This data gives us an insight into the activities of the firms.[3] The aggregate number of patents in large firms and SMEs is rather equal, whereas differences, such as the number of patents per company, can be seen in Table 4.1. The number of patents was disclosed by the biotechnology companies themselves. Thus, they can contain overlapping observations within the same patent families registered by both the European and US patenting regulators.

Based on the data from this survey it was observed with correlation matrix that sales figures correlate positively both with the number of granted patents and the number of patent applications held by a company. Slightly surprisingly, the size of the patent portfolio does not reflect the anticipated future sales [in 2008] also disclosed by the companies. However, the patent counts seem to be closely related to the present R&D expenditures of the companies, and R&D expenditures, in turn, correlate with the anticipated future sales volumes.

Table 4.1 Patent statistics based on survey

SMEs	*Sum*	*Mean*	*Std. Deviation*	*# of companies*
Granted patents	331	4.3	7.3	77
Patent applications	313	4.2	8.9	75
Large enterprises				
Granted patents	253	31.6	51.2	8
Patent applications	21	2.6	3.6	8

[2] See Hermans, Kulvik and Tahvanainen 2005.

[3] The survey ignores the location of patenting (USPTO and EPO) of these granted patents and applications. These aspects are analyzed in more detail later in this paper utilizing new patent data.

The patent statistics from these surveys provide us with a starting point for further examination and analysis. The following two sections describe in more detail both the patenting behaviour of the Finnish biotechnology industry and our empirical results based on analyses of the new data.

4.4 Materials and Methods

Patents usually have a highly skewed value distribution (Harhoff, Scherer and Vopel 2003). That is, few patents have a very high economic value, whereas most patents have a low economic value or none at all. In order to collect data on patents that have at least some economic value we have selected the patents granted in USPTO (United States Patent and Trademark Office) and EPO (European Patent Office) as the patenting process is costly in these patent offices (Moed, Glanzel and Schmoch 2004).

4.4.1 Sources of Data

The data we are using in this paper consist of patents granted in USPTO (Unites States Patent and Trademark Office) and EPO (European Patent Office) between 1 January 1991 and 31 December 2004. Patent data was collected from publicly available sources (USPTO and EPO websites) and from an online patent database (Delphion). The sample consists of 300 observations; 162 from USPTO and 128 from EPO. In addition we collected the patent applications for EPO using the same selection criteria; in this way we wanted to ensure that we also take into account the most recent available information of patenting activity of our target industry. As USPTO has only recently (2000) started to publish the patent applications, we use only EPO patent application data in order to achieve a sufficiently long time series.

The granted patents and patent applications were selected using the following criteria (Figure 4.3):

- EPO and USPTO granted patents (and EPO patent applications) with Finnish priority date assigned to biotechnology related IPC (International Patent Classification) classes[4] and granted between 1 January 1991 and 31 December 2004

[4] For further details of classification see Nikulainen, Pajarinen and Palmberg (2005) Appendix 1. Original sources are Mancusi (2003) and OECD (1994).

- EPO and USPTO granted patents (and EPO patent applications) retrieved by firm names (identified in Finnish Bioindustries' Index of Biotechnology Companies) and granted between 1 January 1991 and 31 December 2004

All selected patents were also assessed individually to verify that they can be considered biotechnology related patents. We additionally divided the patents into pure biotechnology and biotechnology related (such as laboratory technology) classes. Even after this rigorous screening process, only one patent out of three hundred was clearly outside the intended target sample.

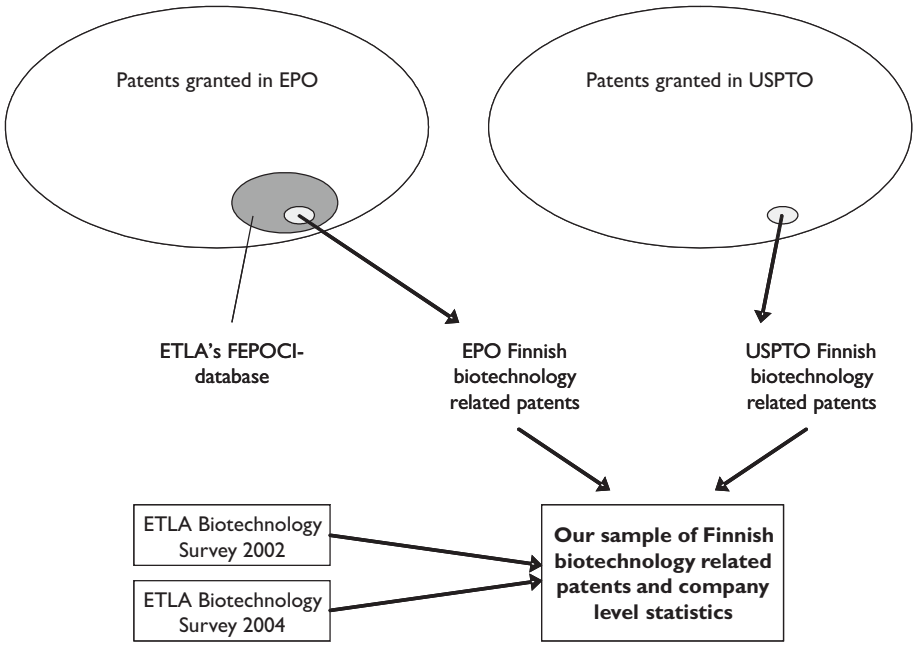


Figure 4.3 Data construction

ETLA's FEPOCI-database consists of patents granted to Finnish assignees and/or patents that have at least one Finnish inventor. The database has very detailed information about the patents, inventors and patent citations (see Nikulainen, Pajarinen and Palmberg 2005 for a more detailed description of the database). From this database we collected citation information for the EPO granted patents. The ETLA Biotechnology surveys were conducted in 2002 and 2004 among Finnish biotechnology companies. The data collected through the surveys was extensive (see Hermans and Luukkonen 2003 and Hermans, Kulvik and Tahvanainen 2005 for a more detailed description). These surveys provided us with a list of companies

operating in Finnish biotechnology, and in addition company specific information regarding, for example, sales, personnel and finances.

Patents are in many cases applied in several locations and hence our data is partly overlapping; the same inventions are patented both in USPTO and EPO belonging thus to the same patent family. As the citations are constructed somewhat differently in the USPTO and the EPO we conduct our analysis by separately analysing the granted patents of each office (Moed, Glanzel and Schmoch 2004). The main focus is, however, on the EPO patents since they provide more comprehensive data for our comparative analysis with respect to other technology areas.

4.4.2 Description of the Data

Our search strategy provided patents that include both pure biotechnology patents and patents related to biotechnology, such as laboratory equipment. The patenting activities within the Finnish biotechnology industry are presented in Table 4.2 EPO/USPTO describes the geographical coverage of the patent.

Table 4.2 Patenting in biotechnology

Descriptive statistics

	Granted patents	Pure biotechnology patents	Biotechnology related patents	Patent applications
EPO	128	92	36	549
USPTO	172	118	54	n.a.
Total	300	210	90	549

The patenting has followed an anticipated path where activity in the early 1990s was relatively low, but with a rapid increase in the late 1990s and early 2000s. Figure 4.4 shows the time-series of granted biotechnology patents in both EPO and USPTO.

As there is a time lag between the original application and the actual grant date, we have also included patent applications published in the EPO to show the most recent recorded activities in biotechnology related patenting. The search criteria for retrieving the patent applications were exactly the same as for the granted patents. Luukkonen (2004) points out that the processing time lags have increased recently.

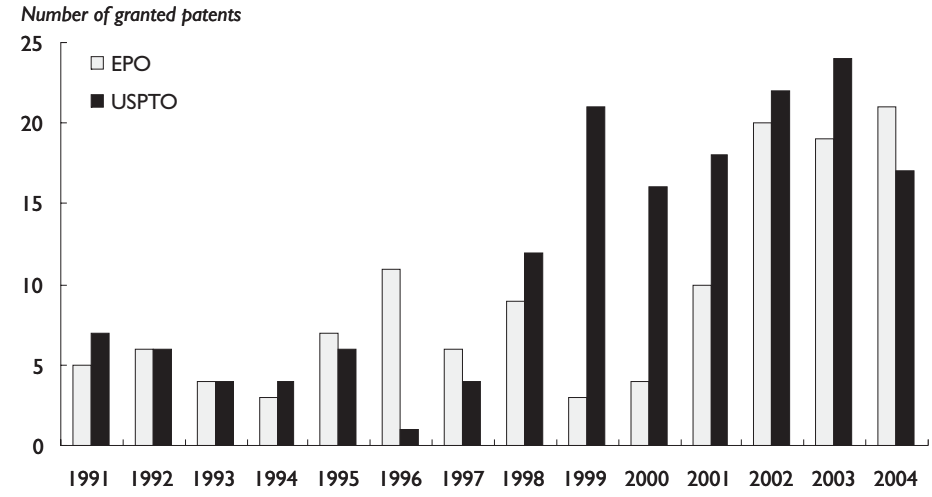
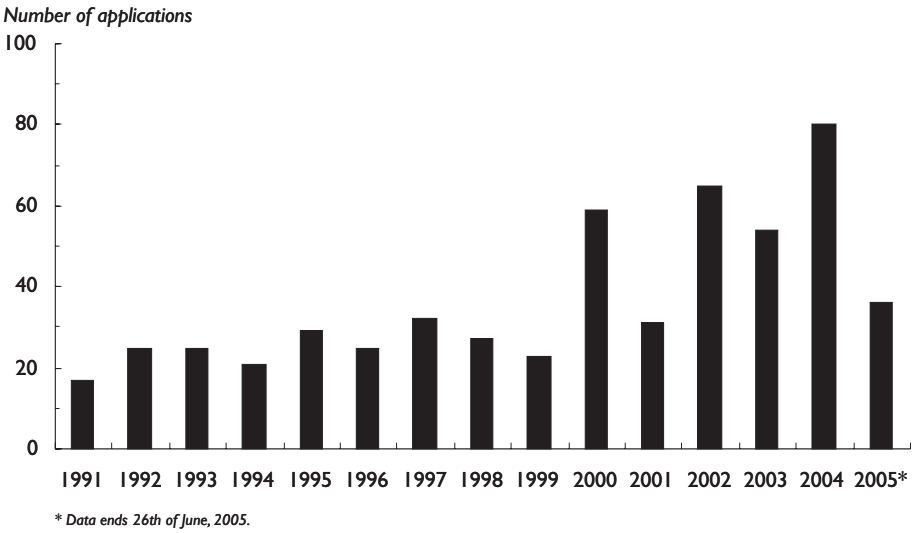


Figure 4.4 Number of granted patents in EPO and USPTO



*Note: data ends 26 June 2005

Figure 4.5 Number of patent applications of the Finnish biotechnology industry in EPO

Figure 4.5 illustrates clearly the increase in patenting activity in the 2000s. This indicates an increase in granted patents in the EPO within the last few years. A comparison of patents granted and applied for provides an interesting result.

Figure 4.6 shows, that rather few applications actually meet the patentability criteria. The percentage of patents granted is approximately 30% of applications. If there indeed are a higher number of applications in biotechnology that fail to become patents when compared to other technologies, it could be an indication that the biotechnology patent applications are of a lower quality. One rationale for this could be that companies are reviewed based on their patenting activity, which might lead to an increase in [low quality] applications. This aspect of company behavior is interesting, but it requires further research as it goes beyond the scope of this study.

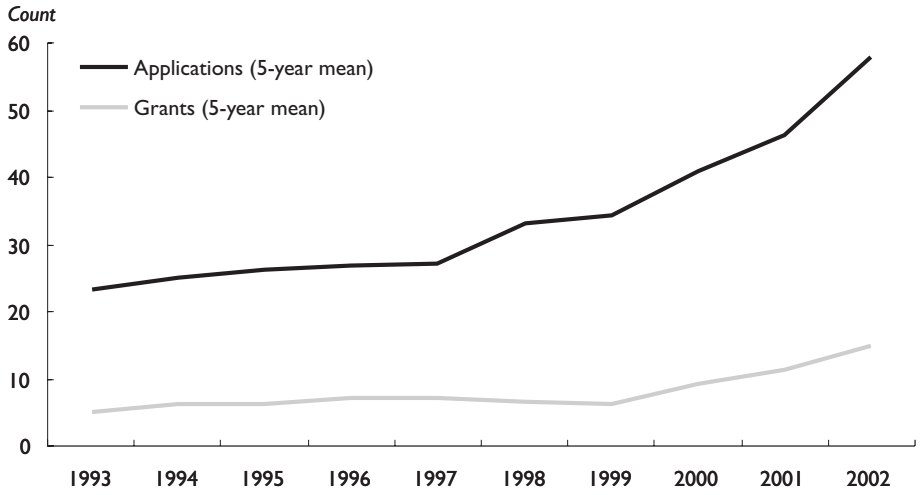


Figure 4.6 Moving average of granted patents and patent applications in EPO

4.4.3 Methods

Unlike backward citations, the forward citations accumulate over time and hence the older patents have higher levels of forward citations than the newer ones. We corrected this truncation bias through standardisation of the number of forward citations annually. The standardised values of forward citations were calculated by subtracting the actual value from the annual average of all citing patents. The difference was then divided by the standard deviation of each year. The number of cited patents was also standardised in the same manner.

Patent citations have been observed to mirror the economic value in some respects. We tested how the backward and forward citations, respectively, predict the present value of anticipated future sales in a re-

gression analysis.[5] The variables collected for each firm were: size, number of cited patents (standardised), number of citing patents (standardised) and number of patents. We transferred the indicators of backward citations and forward citations to company level observations. By doing so, we provided insight into the characteristics of each firm's patent portfolio. In the regression analysis, we also utilised firm level survey data on sales and company specific variables, such as the number of R&D personnel, number of employees and sector dummies.

4.5 Empirical Results

The mean number of citations made each year in USPTO is roughly threefold compared to EPO. The relative difference between the number of citations made in the EPO and USPTO partially stems from the different patent examination processes. In the US system, all relevant patents and other sources are indicated, where as in the EPO only the most relevant patents and other sources are referred to.

4.5.1 Patent Citations within Finnish Biotechnology Patents

The EPO backward citations counts suggest that there has not been a clear change in the basicness of biotechnology related patents within the observed 14 years. Figure 4.7 shows the mean number of citations made by Finnish biotechnology patents each year both in the EPO and the USPTO. Although Figure 4.7 shows a slight upward shift in the EPO patents for the last years of our sample, no obvious trends appear.

The counts of forward citations are presented in Figure 4.8 for both EPO and USPTO. Again, we can see a relative difference between the systems, reflecting the patent examination practices and changes in the way citations are made. We observe a downward trend in the 2000s as older patents evidently have had a longer time to be cited. As presented earlier, we used time corrected forward citations to indicate the technological significance of company patent portfolios.

The values in Tables 4.3 and 4.4 are the mean number of backward/ forward citations by year for each sub-sample. The first column contains all patents in our sample. The next column only includes patents granted to

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[5] We use only the EPO patents as they provide a more accurate picture of the patenting activities.

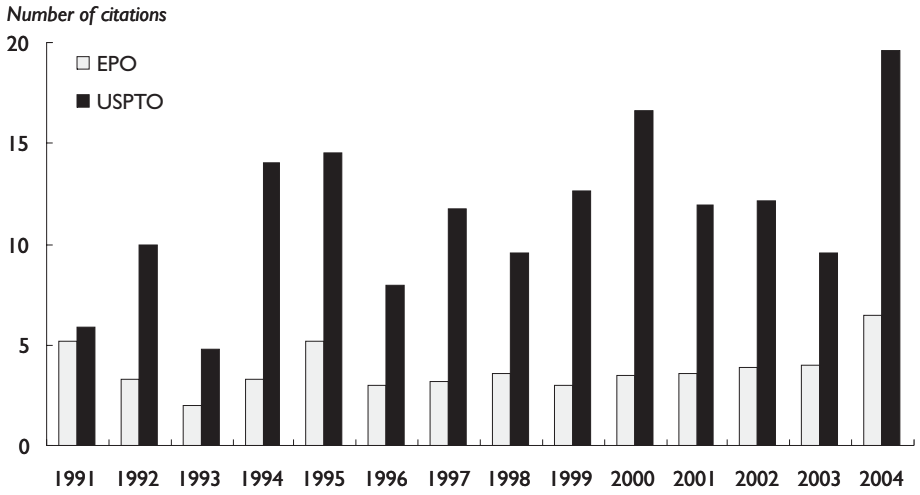

Figure 4.7 **Annual average of backward citations made by Finnish biotechnology patents**

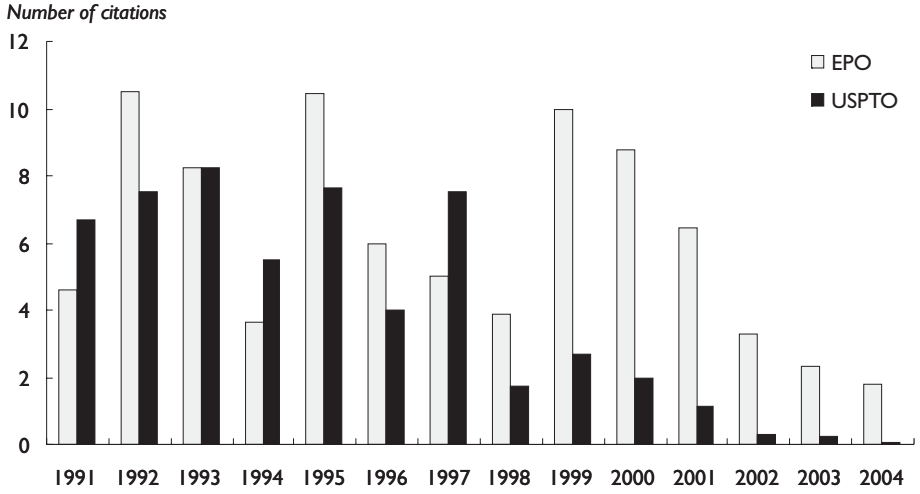

Figure 4.8 **Annual average of forward citations received by Finnish biotechnology patents**

SMEs. Column three contains only the pure biotechnology granted patents (other related patents, such as laboratory equipment, are excluded), and finally in column four we have the pure biotechnology patents granted to SME's. The first set of columns shows the EPO citations made, the second set is the equivalent for USPTO.

Table 4.3 Biotechnology patenting by size and technology (backward citations)

	All patents – backward	SME patents – backward	All pure biotech. – backward	SME pure biotech. – backward	All patents – backward	SME patents – backward	All pure biotech. – backward	SME pure biotech. – backward
	1. (EPO)	**2. (EPO)**	**3. (EPO)**	**4. (EPO)**	**5. (US)**	**6. (US)**	**7. (US)**	**8. (US)**
1991	5.20	5.67	4.50	n.a.	5.86	5.86	10.00	10.00
1992	3.33	4.50	3.60	7.00	10.00	8.75	7.75	3.00
1993	2.00	1.50	2.00	1.50	4.75	4.67	3.00	2.00
1994	3.33	4.00	3.00	n.a.	14.00	14.00	n.a.	n.a.
1995	5.14	5.20	5.00	5.00	14.50	14.50	n.a.	n.a.
1996	3.00	3.67	2.89	3.75	8.00	8.00	8.00	8.00
1997	3.17	3.40	1.67	1.50	11.75	11.75	11.00	11.00
1998	3.56	3.50	2.67	2.40	9.58	10.33	7.10	7.00
1999	3.00	3.00	1.50	1.50	12.62	13.13	8.73	7.60
2000	3.50	3.33	3.33	3.00	16.63	16.63	6.40	5.78
2001	3.60	3.88	2.33	2.25	11.94	12.36	7.27	6.09
2002	3.90	3.88	3.21	3.00	12.09	12.33	6.07	6.00
2003	3.95	3.95	3.67	3.67	9.58	9.59	8.10	7.94
2004	6.43	6.56	6.76	7.00	19.65	19.65	19.56	19.56
Total	3.79	4.00	3.30	3.46	11.50	11.54	8.58	7.83

Table 4.4 Biotechnology patenting by size and technology (forward citations)

	All patents – forward	SME patents – forward	All pure biotech. – forward	SME pure biotech. – forward	All patents – forward	SME patents – forward	All pure biotech. – forward	SME pure biotech. – forward
	1. (EPO)	**2. (EPO)**	**3. (EPO)**	**4. (EPO)**	**5. (US)**	**6. (US)**	**7. (US)**	**8. (US)**
1991	4.60	5.67	3.00	n.a.	6.71	6.71	5.00	5.00
1992	10.50	6.00	12.00	9.00	7.50	9.75	2.25	1.50
1993	8.25	12.50	8.25	12.50	8.25	9.33	4.00	3.50
1994	3.67	0.00	5.50	n.a.	5.50	5.50	n.a.	n.a.
1995	10.43	9.20	14.75	16.00	7.67	7.67	n.a.	n.a.
1996	6.00	3.00	7.11	4.00	4.00	4.00	4.00	4.00
1997	5.00	5.80	5.00	7.00	7.50	7.50	1.00	1.00
1998	3.89	3.63	5.33	5.20	1.75	2.22	1.20	1.57
1999	10.00	10.00	4.50	4.50	2.71	3.06	1.47	1.40
2000	8.75	10.33	7.67	9.50	2.00	2.00	1.20	1.33
2001	6.44	6.38	2.33	1.75	1.11	1.36	0.73	0.91
2002	3.30	3.47	2.00	1.91	0.27	0.29	0.20	0.21
2003	2.32	2.32	2.73	2.73	0.21	0.23	0.20	0.22
2004	1.81	1.89	2.12	2.29	0.06	0.06	0.06	0.06

We can see from Tables 4.3 and 4.4 that SMEs have a slightly higher number of citations made (backward citations) than the larger firms. This is also true when only pure biotechnology patents are observed. A similar

trend appears with the citations received (forward citations). Thus, SMEs seem to patent technologically more significant inventions than larger firms. This might relate to the patenting strategies of companies. Larger firms have the ability and resources to patent even 'insignificant' inventions, because the smaller companies focus on acquiring protection only for the 'significant' inventions.

4.5.2 Comparison to Other Technology Fields

Another way to use this uncorrected data is to compare it with other technologies and observe any differences or changes between levels over time (Table 4.5). The selected comparison groups to biotechnology are: electrical engineering, instruments, chemicals and pharmaceuticals, process engineering, mechanical engineering, consumer goods and civil engineering. Through this comparison we position Finnish biotechnology with respect to other technologies. In addition, we evaluate the differences between large biotechnology firms and SME's (small and medium sized enterprises) and, finally, between pure biotechnology patents and biotechnology related patents. The citation counts are to be used only in comparison to other counts; they provide only a little information about the actual economic value or the technological significance *per se*. The following comparisons to other technologies are based on data from EPO granted patents.

The number of citations received is higher in biotechnology than in comparable sectors. In Table 4.5 biotechnology, electrical engineering, instruments and chemicals all receive more citations on average than the other technologies over several years.

As stated in the analytical background, forward citations reflect both the basicness and the appropriateness and thus the technological significance of an innovation. Most of the forward citations are made by claimants independent of the patent holder, and they reflect a realised interest for the cited technology; consequently, the empirical literature shows a clear association of economic value and technological significance with forward citations. The high number of forward citations in Table 4.5 indicates that the Finnish biotechnology sector has promising future prospects arising from a well-based technological foundation.

We can see that there is some volatility between the biotechnology patents and patents in other fields of technology in Table 4.6. Overall, biotechnology patents perform below other technology fields when citations made are observed, with the exception of years 1995 and 2004. A relatively low number of backward citations indicate a low basicness or novelty of the patents of the Finnish biotechnology industry compared to other fields.

Table 4.5 Comparison to other technologies (forward citations)

Mean citations received

	Bio-technology	Electrical eng.	Instruments	Chemicals	Process eng.	Mechanical eng.	Cons. Goods & civil eng.
1991	4.60		10.60	4.14	3.77***	2.28***	0.83***
1992	10.50	2.83***	9.82	6.88**	3.89***	3.29***	4.46***
1993	8.25	2.18***	5.42**	5.82**	2.93***	2.37***	3.11***
1994	3.67	4.80	7.63	3.67	3.22***	2.97***	2.19***
1995	10.43	5.02***	2.82***	7.66**	3.29***	2.42***	2.78***
1996	6.00	7.28	5.83	4.86	3.81***	2.46***	2.08***
1997	5.00	5.98	6.13	5.91	3.20***	1.72***	2.87***
1998	3.89	5.44***	5.18	4.11	2.52***	2.79*	2.88
1999	10.00	5.67***	4.50***	6.72**	3.14***	2.34***	1.87***
2000	8.75	4.69***	6.10**	6.26**	3.18***	3.37***	2.57***
2001	6.44	6.21	9.06	6.00	2.75***	1.49***	1.25***
2002	3.30	5.58***	3.26	2.73	2.21***	1.52***	1.38***
2003	2.32	5.07***	2.61	3.50**	1.52***	1.12***	1.24***
2004	1.81	5.30***	1.42*	2.82*	1.33***	0.82***	0.58***
Average	6.07	5.44***	4.60***	4.67***	2.64***	1.97***	2.00***

Notes 2:

*** Statistically significant at 1 % level

** Statistically significant at 5 % level

* Statistically significant at 10 % level

Table 4.6 Comparison to other technologies (backward citations)

Mean citations made

	Bio-technology	Electrical eng.	Instruments	Chemicals	Process eng.	Mechanical eng.	Cons.goods & civil eng.
1991	5.20		5.60	2.86***	5.04	5.24	4.50
1992	3.33	4.00	5.00**	4.25*	4.87***	4.03*	4.92**
1993	2.00	3.18**	4.16***	3.86***	4.40***	4.29***	5.00***
1994	3.33	3.64	3.67	3.64	4.11***	4.21***	4.43**
1995	5.14	3.54***	3.43***	4.10***	4.05***	4.75	4.33
1996	3.00	3.26	4.67***	3.33	3.93***	4.24***	4.00**
1997	3.17	3.34	3.17	3.50	4.01***	4.46***	4.69***
1998	3.56	3.82	3.94	3.34	4.57***	4.56***	3.85
1999	3.00	3.48***	4.31***	3.89**	4.06***	3.90***	4.35**
2000	3.50	3.82*	4.86	4.93**	4.19**	4.41***	4.97***
2001	3.60	4.11***	5.06***	3.74	4.60***	4.21**	4.67***
2002	3.90	3.96	4.62**	3.87	4.19	4.42***	4.10
2003	3.95	4.04	5.03***	4.35*	3.99	4.46***	3.95
2004	6.43	3.96***	4.91***	4.78***	4.16***	4.62***	5.37**
Average	3.79	3.83	4.49***	4.02**	4.23***	4.40***	4.49***

Notes: 1991 data on electrical engineering has been excluded due to the small number of patents.

Notes 2: t-test (average unequals the average of citations made in biotechnology patents).

*** Statistically significant at 1 % level

** Statistically significant at 5 % level

* Statistically significant at 10 % level

4.5.3 Company Level Characteristics: Regression Analysis

The first regression model, in Appendix 4.1, yields a positive dependency for backward citations and a negative dependency for SMEs with the present value of actual and expected future sales as the dependent variable. The negative dependency for SMEs implies that small and medium sized companies have a lower sales expectancy than their large counterparts. Both independent variables present a 5 % statistical significance. There also seems to be a dependency between predicted R&D and present value of present and future sales. Trajtenberg, Henderson and Jaffe (1997) observe that the number of backward citations should be more closely related to R&D expenditures than to the company value itself. Thus, high R&D intensity creates a high number of patents (and patent citations), which does not necessarily solely imply direct economic gain. The Finnish biotechnology industry, however, seems to rely on their technological basicness and high R&D intensity as primary sources of value creation logic.

Our second empirical model shows a statistical significance between the number of backward citations and present value of productivity, that is, the present value of actual and anticipated future sales per number of employees. Most notably the backward citations (citations made) predicted significantly the present value of productivity: the more backward citations, the higher the anticipated sales per head potentially in the future. This implies the link between the technological basicness of the invention and company's disclosed future productivity.

It seems that Finnish biotechnology companies within our data do not rely on the applicability or appropriability (measured by forward citations) of their patents in the creation of anticipated future sales schemes. In contrast to that, more emphasis is laid on a basicness (measured by backward citations) of the patents. This observation diverges from the previous empirical findings, which suggest forward citation count as an efficient indicator for market value or productivity measures of the company. This finding might reveal some differences in company valuation schemes between the Finnish biotechnology industry and its international counterparts or it might also reflect the limited scope of our data.

These and other detailed estimation results will be published in a forthcoming article, with preliminary results presented in Appendix 4.1.

4.6 Discussion and Further Research

Industrial renewal is partially based on innovation and creation of new ideas, and patents are one of the most important instruments in the protection of these innovation activities. Therefore patenting activities can be seen as one central measure of the innovation intensity of companies. The volume of international patenting activities in Finnish biotechnology is quite low, but the number of patents and patent applications is rising and we will most likely see a major increase in patenting within a few years due to this increase in activity.

In an infant industry the absolute number of patents in the sector can initially be so low as to induce a confusing effect on the absolute citation counts: new patents have relatively few prior art patents to refer to (low count of backward citations), whereas the few prior art patents might catch an aberrant multitude of citations (high count of forward citations). We can not rule out the possibility of such confusing factors in this research report.

The comparison of backward citations in distinctive fields of technology shows that biotechnology patenting in Finland is slightly below the average of all technologies during our sample period (1991-2004). On the other hand, forward citations (citations received) are higher than in the compared technologies. As stated in the analytical background, backward citations are considered to reflect, in particular, the basicness of an innovation and forward citations both the basicness and the appropriateness.

Our first regression analysis model discloses a statistically significant dependency between backward citations and anticipated sales. It also discloses a negative dependency on SMEs; smaller companies seem unable to catch the value added of patents with a high basicness as well as larger enterprises. We can also see an additional dependency between predicted R&D and the present value of actual and anticipated future sales. The dependency on backward citations remains significant also in the second model with expected productivity as the dependent variable. However, neither of the models shows a dependency between forward citations and the dependent variables.

These findings agree with the literature suggesting that:

1. Small companies could have trouble catching the added value potential of a wide application patent, whereas large enterprises should be able to benefit from a patent with a high degree of basicness (Hall, Jaffe and Trajtenberg 2005).

2. The number of backward citations should be more closely related to R&D expenditures than to the company value itself (Trajtenberg, Henderson and Jaffe 1997). This latter notion deserves some further analysis in the future.

Backward citations are influenced by the applicant whereas forward citations are more independent as most of the citations are made by claimants independent of the patent holder. The high forward citation counts compared to other industries suggest that

a. the Finnish biotechnology sector has a high potential for creating value, but that at the same time

b. the industry itself emphasises the much weaker backward citations and to some extent R&D as markers for present and future earnings, but specifically not the strong forward citations. Related to the literature (Trajtenberg, Henderson and Jaffe 1997), this finding implies that the Finnish biotechnology industry seems to rely on their own technological competence as a source of the company value or their sales anticipation schemes.

Recent patent valuation literature relates forward citation counts, in particular, to the value of the company. We do not find this relation in our data on the Finnish biotechnology industry, which might be due to an insufficient number of relevant cases, or this could reflect either

1. a technology-oriented attitude of the companies or

2. a well-argued value creation mechanism.

On the one hand, if the Finnish biotechnology industry cites inside their own industry but claims they have high expectations for the future, their expectations are highly technology-oriented without a strong market pull (see also *e.g.* Renko et al. 2005). On the other hand, if the citations are outside their own technological field, they show high originality, and their interpretation is well argued. This issue is of great importance in further research.

This study is a first attempt to see how the economic value and technological significance of the Finnish biotechnology industry is developing through patent statistics and it encourages us to see the potential in using patent data in other contexts as well. As the number of Finnish patents in biotechnology is still quite small, an interesting aspect could be a study on biotechnology inventors. This would provide us with a picture on the networks behind inventions and the scientific basis of Finnish biotechnology.

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Appendix 4.1 Results of regression analyses

The first stage of the 2SLS prediction model yields companies' R&D expenditures predicted by the number of PhD:s. The second stage results are presented below.

Table A4.1 Definitions of variables forming the regression analysis model

Variable	Definition
Drug discovery	Sector dummy (1 if related)
Diagnostics	Sector dummy (1 if related)
Biomaterials	Sector dummy (1 if related)
Equipment	Sector dummy (1 if related)
Contract research	Sector dummy (1 if related)
Enzymes	Sector dummy (1 if related)
Food and feed	Sector dummy (1 if related)
R&D staff	Number of employees in R&D
Forward citations	Value of the company patent portfolio, standardised forward citations
Backward citations	Value of the company patent portfolio, standardised backward citations
Number of patents	Number of granted patents
SME	Size dummy (1 if SME)
*	Statistically significant at 10 % level
**	Statistically significant at 5 % level
***	Statistically significant at 1 % level
PVlabour (dependent variable)	Present value of actual and expected future sales / number of employees (Discount factor 20%)
lnPVtotal (dependent variable)	Present value of actual and expected future sales (Discount factor 20%)

Table A4.2 Regression model with the present value of actual and expected future sales as the dependent variable

	R Square	Adjusted R Square
	0.757789559	0.534210691
	Unstandardised Coefficients	
	B	Std. Error
(Constant)	19.829	0.974
Drug discovery	-0.102	1.177
Diagnostics	1.045	1.041
Biomaterials	-1.399	1.178
Equipment	-3.715	3.250
Contract research	1.189	1.496
Enzymes	0.445	1.623
Food and feed	0.800	1.504
Forward citations	0.165	0.585
Backward citations	0.928**	0.341
Number of patents	0.098	0.152
SME	-3.141**	1.105
Predicted R&D (from first stage regression)	1.117*	0.544
Dependent Variable: lnpvtotal		

Table A4.3 Regression model with the present value of anticipated productivity (actual and expected future sales divided by the number of employees) as the dependent variable

	R Square	Adjusted R Square
	0.667070434	0.359750834
	Unstandardised Coefficients	
	B	Std. Error
(Constant)	12.988	34.622
Drug discovery	52.403	41.809
Diagnostics	37.495	36.968
Biomaterials	30.832	41.847
Equipment	-8.590	115.454
Contract research	44.461	53.159
Enzymes	-7.349	57.650
Food and feed	23.632	53.422
Forward citations	10.789	20.797
Backward citations	33.368**	12.124
Number of patents	-1.742	5.400
SME	-41.370	39.252
Predicted R&D (from first stage regression)	-4.762	19.329
Dependent Variable: PVlabour		

CHAPTER 5

Regional Differences in Patterns of Collaboration, Specialisation and Performance

Hermans, Raine – Tahvanainen, Antti-Jussi

5 Regional Differences in Patterns of Collaboration, Specialisation and Performance

5.1 Introduction

Finland's biotechnology industry is agglomerated around several geographically dispersed locations, namely the Helsinki, Turku, Tampere, Kuopio and Oulu regions, of which the Helsinki and Turku regions harbour two thirds of Finland's 110 biotechnology SMEs. All of the regions boast universities active in biotechnological research. This constitutes the starting point of any analysis concerning the spatial distribution of the Finnish biotechnology industry (see *e.g.* Hermans and Luukkonen 2002).

In the present chapter, however, we want to go further and beyond a plain depiction of location.

Based on the in-depth data of the ETLA Survey 2004 our aim is to add new dimensions to the so far two-dimensional picture and complement existing research by mapping and assessing spatial patterns of collaboration, research inputs and outputs, funding and specialisation in the distinctive sectors of the biotechnology industry in Finland. These spatial patterns are crucial factors for a sustainable competitive advantage of any sector, and even more so in a new emerging sector such as the biotechnology industry (Figure 5.1).

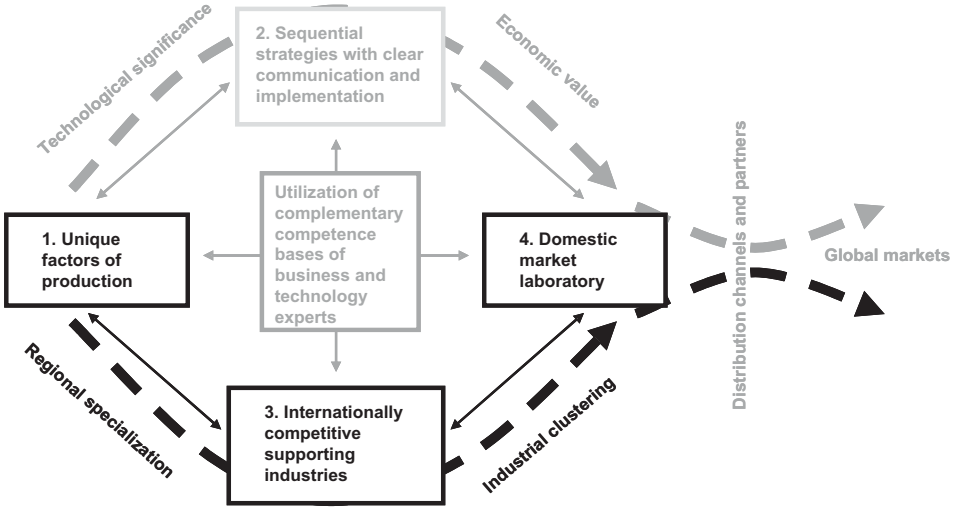

Figure 5.1 Regional specialisation and sustainable technology development

There is an obvious discrepancy between the relatively small size of the country, that of the resident biotechnology industry and the relatively large number of hubs of agglomeration. The academic hubs, all of which feature biotechnology centres, provide facilities and services to the resident companies. These centres are the outcome of the national innovation policy of the early 1990s that focussed strongly on regional development. A decade later criticism has been heard of the establishment and maintenance of five separate hubs as being inefficient in the sense that the industry is dispersed over the country impeding the formation of a critical mass needed to spur the so far modest internally generated growth of sales of the industry (*e.g.* Kafatos *et al.* 2002).

To make the discrepancy more plastic and tangible, we can compare the ratio of country-/industry size and the number of established hubs to those of the USA, the world leader in biotechnology. In raw numbers, the USA has a surface area 30 times larger than that of Finland, a GDP 74 times larger than the Finnish counterpart[1], and a biotechnology industry ten times the size of Finnish biotechnology in the number of firms and 118 times that in terms of sales[2]. However, the USA has only two major and seven minor regions of agglomeration in the biotechnology industry with the former being Boston and San Francisco. Resources are far more concentrated and single hubs constitute larger units by far than those in Finland. A critical mass of companies forming a self-nourishing cluster can be envisioned with ease in this setting. In the light of these figures the criticism of the multicentred structure of Finnish biotechnology seems reasonable at first glance.

The spatial dispersion and the relatively poor performance of the Finnish biotechnology business activities raise a need for a closer analysis of the economic rationale behind the scheme. Such an analysis should be able to reveal and define the role that spatial structures play in the value creation process of knowledge-intensive industries such as biotechnology. The results of the analysis could then serve as a good foundation for drawing implications for technology policy measures aiming at developing more favourable conditions for technological development.

One potential avenue for the analysis would be to explore the reasons behind the spatial structure of industrial activities as driven by the market structure. A central body of literature dealing with the agglomeration of industries is Geographical Economics. Among a multitude of other things, the Geographical Economics literature suggests several economic drivers that result in an agglomerated structure of an industry. These drivers, based

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1 The USA spends 0.77 % of GDP on R&D compared to 0.93 % in Finland.

2 Source: Natiomaster.

on market structures, comprise regional labour pooling and knowledge spill-overs, intra-industry linkages, transaction costs, regional market size, the degree of regional specialisation and the degree of integration between regions. Taking these drivers into account, firms choose their respective locations while maximising their profits.

While entrusting methodically more sophisticated empirical analyses and in-depth theoretical discourses to future research, this chapter takes a first step by seizing the suggestions of the Geographical Economics literature and providing an initial descriptive assessment of some of the proposed drivers of spatial agglomeration and firm performance indicators in the above five regions of Finnish biotechnology as follows:

Section 2 describes R&D collaboration patterns of Finnish biotechnology SMEs serving as a proxy for intra-industry linkages. Section 3 develops indices for identifying patterns of regional specialisation. Section 4 contrasts research inputs as measured by labour and funding to outputs that are quantified by revenues as a performance indicator, while Section 5 brings the chapter to a close with conclusions.

5.2 Regional Collaboration Patterns

In the following section we present descriptive findings on the R&D collaboration patterns of Finnish biotechnology SMEs. The presentation provides comprehensive and graphical insights into the networked structure of the industry. The biotechnology industry collaborates with organisations active both in commercial product development and scientific research. Within the framework of Geographical Economics (*e.g.* Krugman and Venables 1995) R&D collaboration can be interpreted to represent intra-industry linkages, where in addition to conventional materials or substances, the knowledge is often a main intermediate input. These linkages are drivers stimulating agglomeration as firms are apt to lower transaction costs associated with the interaction between firms by clustering near another.

Role of R&D collaboration within the theoretical framework

To give the intra-industry linkages a more hands-on interpretation one can argue that R&D collaboration *within* the biotechnology industry approximates the trading of intermediate inputs used by companies to produce final goods to consumers. This notion is easily defendable, as knowledge, traded and exchanged by biotechnology firms largely through R&D collaboration, is the most important single production factor in knowledge-intensive industries. Moreover, R&D collaboration *between the local academic sector and the biotechnology*

industry should be understood as a more unilateral input linkage, as biotechnology firms utilise local knowledge resources provided by academia in its operations. In order to further illustrate the significance of R&D collaboration as a mediator of knowledge we can take a brief look at the associated literature.

R&D collaboration as a critical success factor for research-intensive companies

Mowery (1998) summarises the advantages of collaboration as suggested by the economics literature in general. These include the ability to capture knowledge-spillovers by collaboration partners that might be otherwise wasted, the reduction of R&D duplication and saving of resources invested in it, the utilisation of scale economies in R&D, the acceleration of commercialisation of new technologies, a quicker transfer of technology from universities and other research organisations to the industry, an enhanced access to the capabilities of these organisations by the industry, and lastly, the chance to establish a common technological vision among the industry resulting in a more focused and structured approach towards it.

The literature suggests that there is a clear negligence concerning the potential advantages of collaboration in biotechnology (see Shan, Walker and Kogut 1994, Nilsson 2001 as well as Powell 1998). A too introvert attitude compromises the ability of firms to identify and capture emerging opportunities, be they technological or commercial, in the absence of a supportive and complementary network.

Because the human capital of a particular company is limited to that provided by the people employed and committed to the company, a possible lack of abilities, experience, and skills needed for a successful completion of R&D projects must be compensated for by accessing external sources. While the human capital requirements differ from project to project, its supply must be flexible for the company in order to retain as lean a cost structure as possible – an ultimate requirement for young research-intensive companies often without internally generated revenue streams.

As opposed to hiring ever new employees to compensate for the lack of human capital, collaboration with other organisations provides several advantages. Firstly, compensation between collaboration partners does not necessarily require monetary flows during the project. Partners can agree, for instance, on splitting future revenues generated by the outcome of the project according to the amount of input provided by each partner. Secondly, instead of acquiring the limited abilities of single individuals, collaboration provides access to the collective of generative intangibles of the partner with a far higher potential of creating value, by definition, than can be

provided by additional individuals employed. Finally, partners can be chosen with project specific requirements in mind and, even more importantly, released from the collaboration after the completion of the project or an *ex ante* specified part of it, resulting thereby in the flexibility spoken of above.

Findings of the ETLA Survey 2004 on regional R&D collaboration patterns

Figure 5.2 presents a geographical display of the number of firms[3] collaborating between any two domestic regions. It is important to state right at the beginning that the figure does not just depict collaborative ties with other biotechnology firms but also those with academic institutions, research centres, firms in other industries and clinical units. One of the two collaborating partners, however, is always a biotechnology company.

On a global scale, domestic grounds are the single most frequent region for the collaboration of Finnish biotechnology firms, with 94.5% of companies collaborating with a partner inside Finnish borders. The lack of cultural barriers, a uniform regulatory framework, shorter distances and a supportive technology policy entail lower transaction costs as opposed to networking with foreign R&D partners rendering the finding rather plausible. In Figure 5.2, the thickness of the connecting lines and local dots is proportional to the *number* of collaborating firms, where the dots represent collaboration within the particular region itself. As one might expect based on the sheer number of resident firms in the regions, collaboration volumes are highest between the capital and Turku regions. Particularly the Helsinki region seems to constitute an important collaboration hub as there is a high degree of collaboration between this region and every other major region, as well as many of the most peripheral regions. No other region exhibits as much collaborating activity. Figure A5.1 in the appendix underlines the finding showing, separately for each region, the regions' firm *shares* that have established collaborative arrangements with firms in other regions. Of the five major biotechnology regions in Finland, Tampere seems to be the most inactive collaborator as expressed by both the number and the share of collaborating companies. With Tampere employing almost as many people (8%) as Kuopio and Oulu together (9%), the finding cannot be founded solely on differences in volume. Collaboration among companies in the peripheries is rather rare, although not completely non-existent.

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[3] Not to be interpreted as the *share* of firms collaborating in a given region. A representation of collaboration activities in the form of regional firm shares is shown in Figure A1 in the appendix to this chapter.

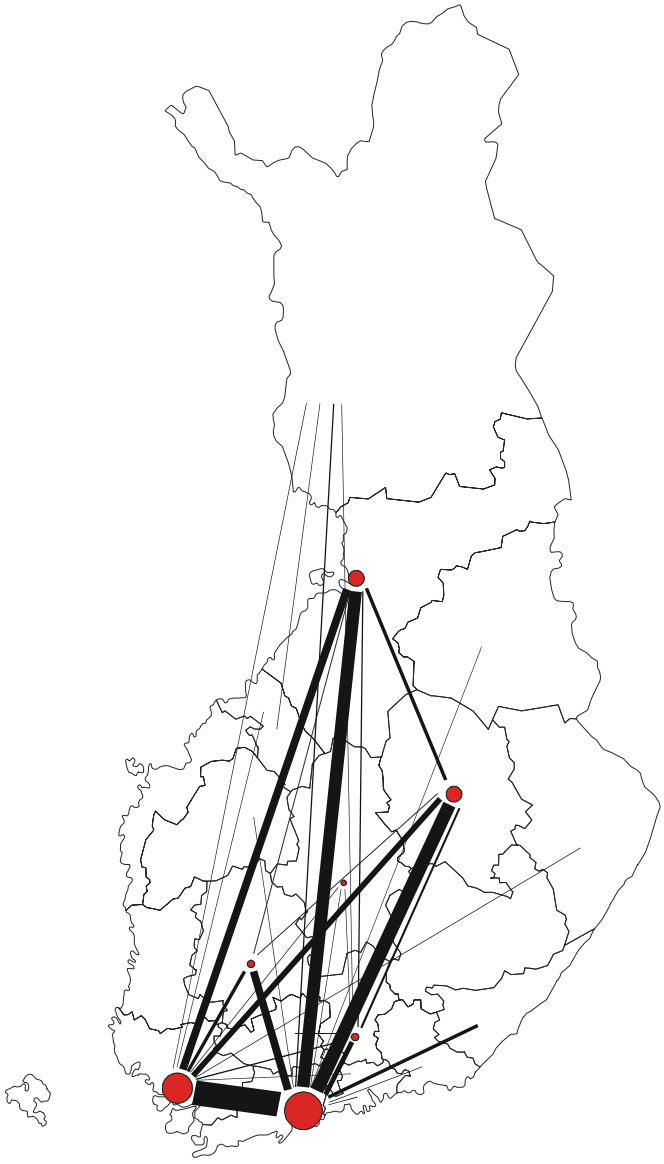

Figure 5.2 Domestic R&D collaboration of the Finnish biotechnology industry in 2003

An important observation that deserves special attention is the seemingly profound significance of intra-region collaboration depicted by the dots in Figure 5.2 and Figure A5.1. In the Helsinki and Turku regions, in particular, intra-regional collaboration is the most important single mode of collaboration. Also in other regions collaboration with companies in close proximity is at least as frequent as with any other region. This is an indication in line with

Geographical Economics predicting the spatial clustering of companies that connect to each other via intermediate input relations, here R&D collaboration. The theory predicts that in the presence of low transport costs arising from the delivery of final goods or services from the location of its origin to the final customer, companies depending on intermediate inputs of each other will minimise transaction costs emerging from trading these inputs by locating near each other instead of necessarily locating in close proximity of the final consumer. Since exports constitute over 90% of the sales of Finnish biotechnology companies, the exact location within Finland can be expected to have only a marginal impact on the overall transport costs. Thus, minimising transaction costs among producers of intermediates through clustering becomes reasonable.

In the case of biotechnology, the effect might be even stronger because knowledge, the intermediate input in question, can be effectively transferred between partners only if they maintain a very close relationship to each other (Nonaka and Takeuchi 1995). However, if the earnings are mostly generated by royalties or other licensing payments, some other drivers steer the location. For instance, once the licensing agreement has been negotiated, there is more pressure to locate the company's activities in line with the availability of resources needed in further R&D activities and a location of future collaborators and customers. It is a key issue for a peripheral country far from the main markets to illustrate how it can build a network strong enough, which combines complementary competencies and creates a critical mass for companies without needing to relocate near the main market.

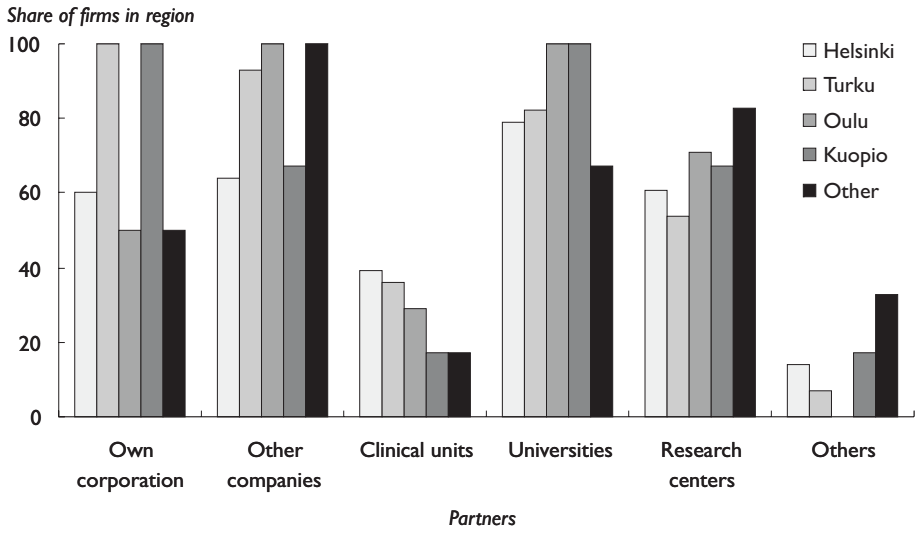

Figure 5.3 R&D collaboration partners by domestic region

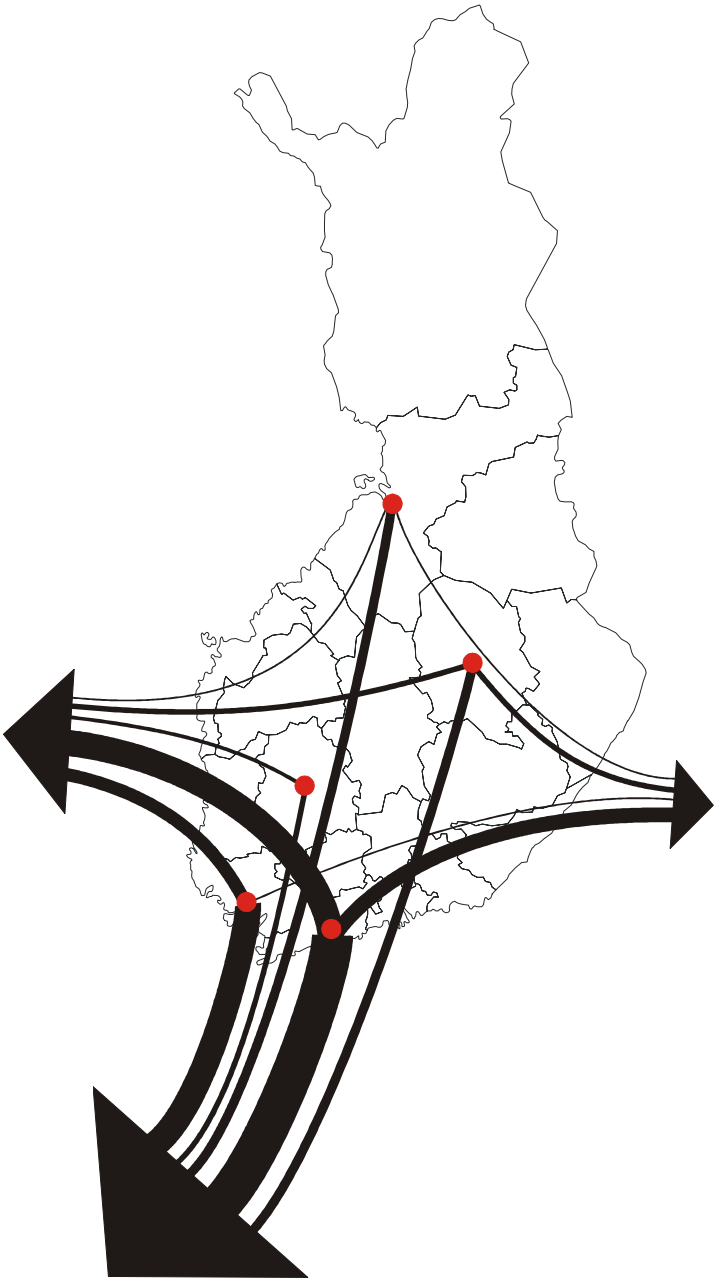

Figure 5.4 **International R&D collaboration of the Finnish biotechnology industry in 2003**

The shares of companies, which indicate collaboration with the different types of partners, are displayed in Figure 5.3 by domestic region. Most frequent collaboration partners are other companies (including also non-

biotechnology companies) and universities. The share of companies collaborating with their parent or sister companies has been computed from the population of companies that are part of a corporation. The volatility from region to region is partly explained by the fairly low number of companies being in a corporative organisational structure in the first place. Clinical units seem to be a less frequent collaboration partner because there are many sectors unrelated to health care.

Figure 5.4 is a graphical illustration of R&D collaboration volumes to regions outside Finland. Identified regions comprise the EU, North America and Asia. For reasons of geographical clarity we have included firms from the five major domestic biotechnology centres only, as peripheries have little effect on the results. Again, the thickness of the arrows indicates the number of firms collaborating with the particular continents. It is obvious that the EU region (downward arrow) represents the major foreign region of collaboration for Finnish biotechnology companies with 57.5% of sample companies having collaborating arrangements with EU partners outside Finland.

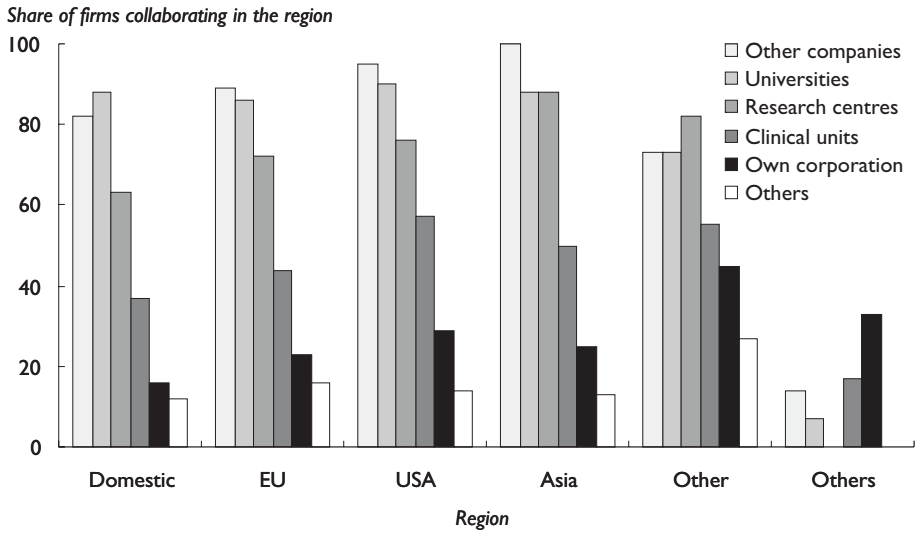

Figure 5.5 Collaboration partners by foreign collaboration region

North America represents the second most important region with 30% of the sample companies having R&D partners in that region. In particular, firms active in equipment development (45% of sample companies in this sector), drug development (33%) and contract production (31%) have established partnerships in North America. Enzymes, food and feed, as well as diagnostic services, follow closely with just below 30% of them having collaboration partners in this region.

Asia constitutes a less frequent region of collaboration in R&D, with 14% of all sample companies showing collaboration arrangements with the Asia-Pacific region. Enzymes, as well as food and feed, are those sectors displaying the highest collaboration frequency with this region.

Figure 5.5 shows the types of collaboration partners encountered in the different collaboration regions worldwide. It is striking that the relative frequency of partner types remains almost constant from region to region. It seems that no region can boast a comparative advantage in offering better opportunities or a higher quality of supply in any type of collaboration partnership. Other companies (*e.g.* clients, sub-contractors, competitors, venture partners) seem to be the most frequent type of partner in every region except on domestic ground.

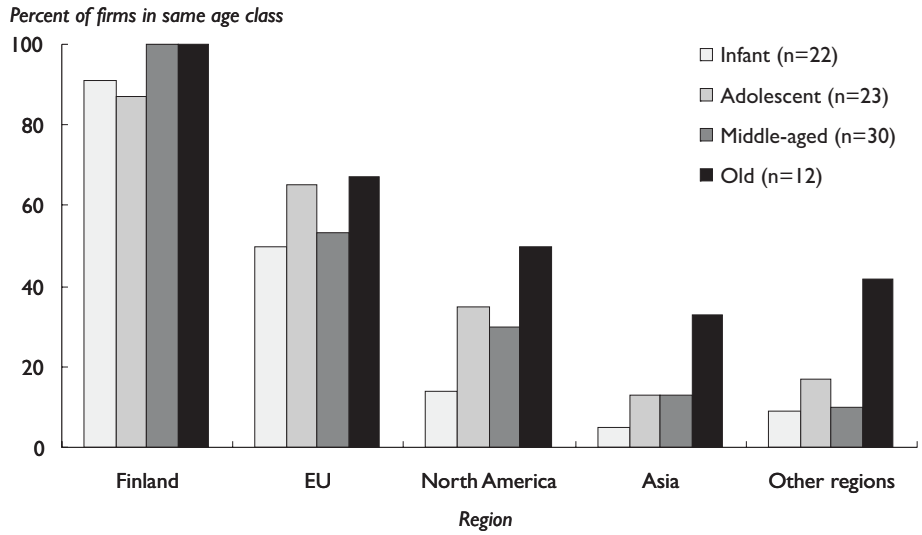

Figure 5.6 R&D collaboration regions by age

Figure 5.6 reveals that age does not have an overwhelming effect on the propensity to co-operate in R&D by region, except for the old age companies (≥ 24 years) that collaborate with foreign partners more frequently than their younger counterparts. It seems also that the youngest companies (less than 5 years old) tend to co-operate slightly less than their older companions. The effect is amplified with the growing distance to the collaboration region.

5.3 Regional Specialisation

This section will examine the five regions and provide a picture with further details by determining the regions' local specialisation patterns.

According to Krugman and Venables (1996), in fact, agglomeration and specialisation are phenomena that are closely linked to each other. While Krugman and Venables (1996) build their framework to model specialised agglomeration on the international level between countries, it is easily transferable to a national scenario with regions in lieu of countries. For instance, Martin and Rogers (1995), as well as Monfort and Nicolini (2000), extend the approach to an intra-country framework.

Vital preconditions for the specialised location of economic activities are again the presence of intermediate input linkages among firms of the industry and a low trade costs between regions. When both conditions are satisfied, a region with a strong initial position in some sector (*e.g.* drug development, diagnostics, biomaterial) in terms of the number of intermediate and final goods producers might gain a self-energising advantage over other regions, as final goods producers in that particular sector prefer the region due to the relatively larger base of intermediate producers. When trade costs are low enough, the benefits of locating near the intermediate producers as opposed to final markets outweigh the costs of exporting outside the region. The result is a strengthening of specialisation and, simultaneously, agglomeration in the region. Intermediate producers in the same sector, in turn, prefer to locate near final goods producers to minimise costs. It follows that each sector of the industry will tend to concentrate in some region.

Hermans (2004) labels the level of integration within a single country *extreme integration*, a level of integration at which trade costs are minimal. At this stage we should point out, however, that in the Finnish case the state of extreme integration is affected to some extent by the active regional policy of the 1990s subsidising technology development activities in the geographical peripheries of the country. This has left core areas, situated mainly in the south of the country, at a relative disadvantage by elevating relative trade costs from core areas to peripheries.

With this said, we will show next descriptively whether and how the five regions of agglomeration show signs of specialisation. All of the constructed indices measure different aspects indicating the degree of a region's specialisation in any of the sectors of the biotechnology industry. We will go through each of the indices separately before combining them into a single composite index serving as a concise synopsis.

Labour input specialisation. The following two tables depict specialisation as measured by two different labour input shares. In Table 5.1 the grey background indicates that a given *sector* employs a higher proportion of the labour in a region than the sector does on average in Finland[4]. For instance, drug development employs 26.8 % of labour of the small biotechnology industry in Finland. 37 % of Turku region's labour force is involved in drug development and, thus, the region is specialised in that sector in terms of labour input.

Table 5.1 Labour specialisation by sector

	Finland	Helsinki	Turku	Tampere	Kuopio	Oulu
Total	100.0 %	41.9 %	24.3 %	8.6 %	5.9 %	2.5 %
Drug developm	26.8 %	26.4 %	37.0 %	19.9 %	46.0 %	33.6 %
Diagnostics	37.3 %	46.0 %	41.5 %	22.9 %	80.3 %	31.1 %
Biomaterials	11.0 %	6.5 %	3.4 %	75.6 %	4.4 %	25.2 %
Bioinformatics	3.8 %	7.2 %	3.1 %	0.0 %	0.0 %	0.0 %
Enzymes	19.4 %	27.5 %	12.7 %	0.0 %	0.0 %	0.0 %
Food and feed	19.7 %	2.2 %	25.9 %	0.0 %	0.0 %	1.7 %
Agroforest	1.5 %	1.9 %	0.0 %	0.0 %	0.0 %	15.1 %
Environment	2.4 %	1.5 %	4.5 %	0.0 %	0.0 %	0.0 %
R&D services	15.9 %	8.7 %	26.0 %	19.9 %	35.8 %	43.7 %

In Table 5.2 the grey background signifies that a *region* employs a higher proportion of labour of a specific sector than the country does on a national level[5]. For instance, the Helsinki region employs 41.3 % of the labour active in drug development in Finland, whereas the Turku region employs only 33.5 %. However, with Helsinki employing 41.9 % of the labour in the entire biotechnology industry, it is not specialised in drug development (41.3 % < 41.9 %). By contrast, the Turku region is specialised in drug development (33.5 % > 24.3 %).

Table 5.2 Labour specialisation by region

	Total	Drug dev.	Diagnost.	Biomat.	Bioinf.	Enzymes	Food&feed	Agroforest	Environm.	R&Dserv.
Finland	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %
Helsinki	41.9 %	41.3 %	51.8 %	25.0 %	80.2 %	59.5 %	4.8 %	54.3 %	26.5 %	22.9 %
Turku	24.3 %	33.5 %	27.1 %	7.4 %	19.8 %	15.9 %	32.0 %	0.0 %	45.1 %	39.7 %
Tampere	8.6 %	6.4 %	5.3 %	59.4 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	10.8 %
Kuopio	5.9 %	10.1 %	12.6 %	2.3 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	13.2 %
Oulu	2.5 %	3.2 %	2.1 %	5.9 %	0.0 %	0.0 %	0.2 %	25.7 %	0.0 %	7.0 %

[4] The formal condition for flagging a quotient is $\frac{L_{ij}}{L_j} > \frac{L_i}{L}$, where L is labour, i denotes the sector of the biotechnology industry and j indicates the region.

[5] The formal condition for flagging a quotient is $\frac{L_{ij}}{L_i} > \frac{L_j}{L}$, where L is labour, i denotes the sector of the biotechnology industry and j indicates the region.

Sales output specialisation. The second set of tables measures specialisation with two different sales output shares. In Table 5.3 the grey background indicates that a sector's sales share of a region's total sales exceeds that sector's sales share of the total sales of the entire industry[6]. For instance, biomaterial-based sales are about 4.2 % of the total sales of the small biotechnology industry while constituting a staggering 93.6 % of the sales of the Tampere region. According to this measurement, Tampere region is specialised in the production of biomaterials.

Table 5.3 Sales specialisation by sector

	Finland	Helsinki	Turku	Tampere	Kuopio	Oulu
Total	100.0 %	59.6 %	15.9 %	2.9 %	1.3 %	0.8 %
Drug developm	30.5 %	41.8 %	20.2 %	1.3 %	32.5 %	33.6 %
Diagnostics	19.2 %	24.6 %	16.3 %	6.4 %	70.5 %	13.5 %
Biomaterials	4.2 %	1.6 %	2.5 %	93.6 %	1.9 %	13.0 %
Bioinformatics	0.3 %	0.3 %	1.1 %	0.0 %	0.0 %	0.0 %
Enzymes	46.7 %	36.4 %	53.9 %	0.0 %	0.0 %	0.0 %
Food and feed	25.4 %	3.1 %	61.7 %	0.0 %	0.0 %	3.3 %
Agroforest	1.4 %	1.1 %	0.0 %	0.0 %	0.0 %	2.6 %
Environment	1.1 %	0.2 %	1.4 %	0.0 %	0.0 %	0.0 %
R&D services	4.5 %	1.8 %	10.5 %	1.3 %	19.3 %	44.9 %

Table 5.4 depicts regional specialisation as approximated by regional sales shares of the total sales of a given sector[7]. For instance, the Tampere region generates only 2.9 % of the total biotechnology industry sales in Finland. Nevertheless, one could say that the region is highly specialised in the production of biomaterials, as it generates 64.7 % of the sales in this sector on a national level.

Table 5.4 Sales specialisation by region

	Total	Drug dev.	Diagnost.	Biomat.	Bioinf.	Enzymes	Food&feed	Agroforest	Environm.	R&Dserv.
Finland	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %
Helsinki	59.6 %	81.7 %	76.1 %	22.7 %	48.7 %	46.4 %	7.3 %	44.0 %	10.8 %	23.1 %
Turku	15.9 %	10.5 %	13.4 %	9.5 %	51.3 %	18.3 %	38.5 %	0.0 %	18.7 %	36.6 %
Tampere	2.9 %	0.1 %	1.0 %	64.7 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	0.8 %
Kuopio	1.3 %	1.4 %	4.9 %	0.6 %	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %	5.6 %
Oulu	0.8 %	0.9 %	0.6 %	2.5 %	0.0 %	0.0 %	0.1 %	1.5 %	0.0 %	8.0 %

[6] The formal condition for flagging a quotient is $\frac{S_{ij}}{S_j} > \frac{S_i}{S}$, where *S* stands for sales, *i* denotes the sector of the biotechnology industry and *j* indicates the region.

[7] The formal condition for flagging a quotient is $\frac{S_{ij}}{S_i} > \frac{S_j}{S}$, where *S* stands for sales, *i* denotes the sector of the biotechnology industry and *j* indicates the region.

Productivity (input-output) specialisation. While Tables 5.1 and 5.2 observed specialisation as measured by input factors, more precisely labour shares, and Tables 5.3 and 5.4 by output, namely sales, Table 5.5 combines these two and measures specialisation by labour productivity as indicated by sales per worker. The grey flag denotes that the per head sales in a particular region and a particular industrial sector exceeds that sector's average per head sales[8]. For instance, sales per worker in drug development is 196 061 euros on average in Finland. The corresponding measure of productivity is 310 547 euros in the Helsinki region. Consequently, the region is specialised in drug development in terms of productivity.

Table 5.5 Labour productivity by region

	Total	Drug dev.	Diagnost.	Biomat.	Bioinf.	Enzymes	Food&feed	Agroforest	Environm.	R&Dserv.
Finland	138 032	156 805	71 279	53 300	11 927	333 240	178 165	133 441	65 498	39 444
Helsinki	196 061	310 547	104 589	48 451	7 234	259 666	270 630	108 041	26 661	39 850
Turku	90 141	49 261	35 316	68 312	30 971	382 548	214 400	0	27 150	36 400
Tampere	46 936	3 097	13 184	58 076	0	0	0	0	0	3 097
Kuopio	31 208	22 086	27 408	13 381	0	0	0	0	0	16 829
Oulu	43 838	43 816	19 041	22 549	0	0	85 649	7 579	0	45 090

Now that we have obtained a fairly detailed and in-depth depiction of the regional specialisation patterns, it might be valuable to combine the above indices into one single index that draws us a more concise picture. To get one coherent composite index of specialisation, we first transform the single indices as follows.

Composite index of specialisation. We first assign the value one (1) to all flagged observations in every single index. Those observations, that are not flagged, are assigned the value zero (0). As a result, we obtain one matrix for each single index that exhibits whether a region is specialised in any of the sectors with respect to the particular index. Combining all five matrices by simply adding the transformed values, we obtain a compound index of regional specialisation. The index values range from zero to five, with 5 indicating strong specialisation and meaning that the particular region is specialised in the particular sector as measured by all five single indices. Table 5.6 exhibits the compound index for each of the five regions observed.

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[8] The formal condition for flagging a quotient is $\frac{S_{ij}}{L_i} > \frac{S_i}{L_i}$, where L is labour, S stands for sales, i denotes the sector of the biotechnology industry and j indicates the region.

Table 5.6 Composite index of specialization

Region	Drug dev.	Diagnost.	Biomat.	Bioinf.	Enzymes	Food&feed	Agroforest	Environm.	R&Dserv.
Helsinki	op 3	5	0	ip 2	ip 2	1	ip 2	0	1
Turku	ip 2	ip 2	1	op 3	op 3	5	0	4	4
Tampere	0	0	5	0	0	0	0	0	ip 2
Kuopio	4	4	0	0	0	0	0	0	4
Oulu	4	0	4	0	0	0	4	0	5

As revealed by Table 5.6, one can indeed observe specialisation patterns among the five regions, especially when only fields of highest specialisation are regarded. The Helsinki region is specialised in diagnostics, Turku in food and feed, Tampere in biomaterials and Oulu in providing R&D services to other companies. Kuopio does not exhibit a field of strongest specialisation, but has a fairly strong focus on drug development and diagnostics in addition to R&D services. The Turku region is the most versatile with fairly strong indices in environmental applications and R&D services as well as significant indices in bioinformatics and enzymes. Also drug development and diagnostics are sectors of focus as measured by input based specialisation. At this point it must be pointed out that R&D services cannot be regarded as a sector of its own, as it can encompass services of any of the other sectors. It is rather a way of business. Nevertheless, companies specialising in R&D services operate a distinct business model and distinguish themselves often strongly from internal R&D-oriented companies. They deserve, therefore, a separate treatment in the index.

In addition to showing the regional fields of specialisation, Table 5.6 provides a cross-section of the development of regional industry structures in the chronological dimension. With the figures marked with "*ip*" indicating specialisation as measured by input and those marked with "*op*" standing for output specialisation, we can infer the regions' alleged directions of development. Helsinki is strongest in diagnostics investing heavily in it and simultaneously creating large revenues in an efficient manner as measured by per head sales. Helsinki's drug development sector is mature in the sense that it boasts large sales based on efficient processes that increase the per head in-flow of cash, although it is not specialised in terms of input. Bioinformatics, enzymes and the agro-forest sectors can be assumed to have great priority in the region as it has invested heavily in them in terms of labour. However, returns on the investments have not yet been realised leaving these sectors a promise for the future. One might argue that they are in an infant state of their life-cycle.

Turku has a very strong food and feed sector and comparatively mature environmental, bioinformatics and enzymes sectors. Additionally, the region invests heavily in drug development and diagnostics displaying above average employment shares. Having said that, Turku's biomaterials and enzymes

sectors are doing comparatively well as sales are generated efficiently without investing super-normally in terms of the number of people employed.

Kuopio is strengthening its drug development and diagnostics sectors that do not seem to be productive yet compared to the entire sectors' averages. At the same time Oulu has invested in biomaterials, drug development and agro-forestry creating expectations for the future in these sectors, while having a past in R&D services so far. It should be emphasised at this point that most biomaterial companies in Oulu develop solutions that are *not* perceived to represent biomaterials as defined according to the current conception, which encompasses mainly *in vivo* products. As the categorisation of activities in biotechnology is often a rather ambiguous task, Oulu's biomaterial companies could just as easily be assigned to the sectors of food and feed and agriculture. Be that as it may, for a region quite isolated in the geographical sense and rather small in terms of sise, Oulu spreads resources over a relatively wide sector base. In contrast, Tampere stands out from all the regions by focussing very determinedly on biomaterials creating major success stories in this sector.

Table 5.7 Krugman's (1991a) Regional Divergence Index within the small and medium-sized biotechnology industry

SME Personnel	Helsinki region	Turku region	Tampere region	Kuopio region	Oulu region
Helsinki region		0.399	0.767	0.648	0.581
Turku region	0.399		0.576	0.285	0.413
Tampere region	0.767	0.576		0.644	0.495
Kuopio region	0.648	0.285	0.644		0.37
Oulu region	0.581	0.413	0.495	0.37	
Other regions	0.629	0.748	1	0.995	0.886
Average	**0.605**	**0.484**	**0.696**	**0.588**	**0.549**

To wrap up the discourse on the specialisation patterns of the small Finnish biotechnology industry, we compare the regions' degree of specialisation based on the Regional Divergence Index by Krugman (1991b)[9]. The index measures how different the industry structures of any two regions are. Here, we apply the index to measure the regional differences within the Finnish biotechnology industry. Table 5.7 cross-tabulates the index over all five regions with the value zero indicating a non-existent difference and the value one indicating a large difference in industry structures. It is possible to

[9] $\sum_i \left| s_i - s_i^* \right|$, where s_i is the share of sector *i* in total biotechnology manufacturing employment in some region and * indicates refers to some other region. In addition, we have normalised the index outcomes to range between 0 and 1.

calculate the average deviation of industry structure for all regions separately. The averages back up our prior findings. Tampere is the most specialised region of all with Helsinki following close behind. On the other extreme, Turku resembles the average structures of Finland more than any other as its activities are quite extensive in most of the sectors.

A final comment concerning specialisation must be issued here. Specialisation in a given sector does not mean specialisation in, for example, general drug development. There might still be considerable differences in the research substance of two distinct regions focussing on the same sector as measured by our indices, because both regions are probably specialised in specific niches of a certain sector. While one region might conduct research related to health care solutions in cardiovascular diseases, the other could be specialised in neurological disorders. Furthermore, research in one sector can have positive externality effects on other sectors nearby through knowledge spillovers. For instance, in this example first-rate medical research does not necessarily create large-scale pharmaceutical industry plants in the region, but it can contribute extensively to the development, growth and success of some other closely related sectors with strong, even mature, local industries such as diagnostics or enzymes.

5.4 Agglomeration of Business Activity

5.4.1 Spatial Distribution of Research Inputs and Sales Outputs

In the previous two sections we have elaborated in-depth on two of the major drivers behind spatial agglomeration, namely intermediate input trade as proxied by R&D collaboration and specialisation of economic activity measured as relative shares of labour input and sales output. This chapter sheds light upon the agglomeration patterns themselves in more detail.

Figure 5.7 places all Finnish small and medium sized biotechnology companies on the map. The height of the pillars in the figure represents the number of companies resident in the particular area. The multi-centred structure of the industry is plainly visible with local agglomerations in the Helsinki, Turku, Tampere, Oulu and Kuopio regions. For the purposes of providing new insights, we will present in the following the spatial patterns of employment, research inputs and sales of the industry that can then be related to the number of firms in each region. Thereby, it is possible to deduce information on the true volume of business activities in the regions instead of relying on mere firm frequencies as a proxy. At this point, we want to emphasise again that the underlying figures are, as

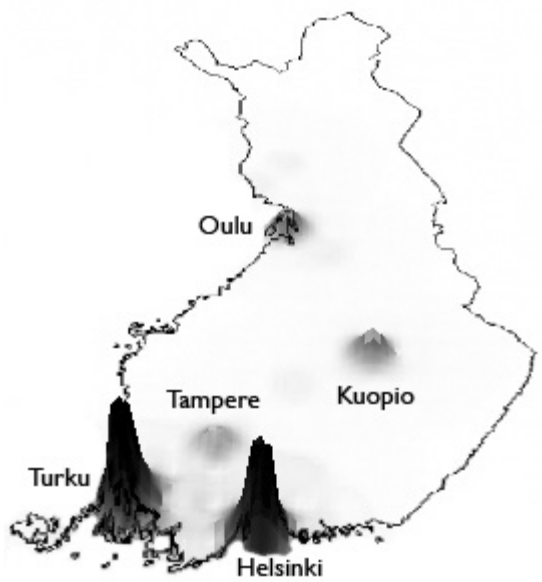

Figure 5.7 Distribution of biotechnology SMEs in Finland[10]

throughout the whole of this chapter, based on the small- and medium sized biotechnology industry *excluding all large biotechnology related companies* resident in Finland. Being extreme outliers, the inclusion of large companies in the sample would render the results senseless. For instance, some of the large corporations excluded from the analysis employ more than twice as many employees than the SME industry as a whole. Also sales figures of single large corporations exceed the total sales of the entire SME industry many times over. This must be kept in mind while interpreting our results.

Figure 5.8 is a graphical illustration of the employment distribution of the Finnish SME biotechnology industry. The Helsinki and Turku regions clearly boast most labour with Lahti, Tampere and Kuopio following.

Although the Oulu region accommodates over 10 % of companies, more than Tampere, Kuopio or Lahti, the number of employees in the region is comparatively low. This implies that the average company size is rather small as illustrated in Table 5.8.

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[10] Subsidiaries excluded.

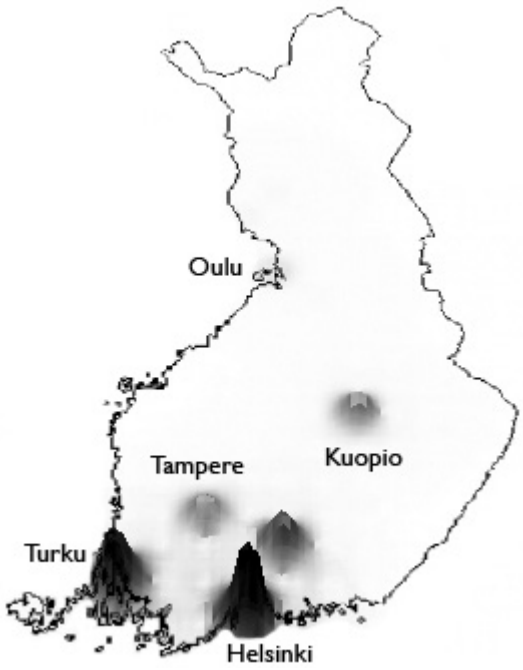

Figure 5.8 Spatial distribution of labour in the biotechnology industry 2003/4[11]

Table 5.8 Average size of companies (number of employees) by region

Region	N	Mean	Std. Deviation	Minimum	Maximum
Helsinki	35	25	40.229	0	174
Turku	31	16	16.513	1	65
Tampere	6	34	34.703	3	75
Kuopio	7	11	9.798	1	30
Oulu	9	6	6.333	0	18
Other	9	43	75.09	2	238
All	97	22	36.046	0	238

Given that Lahti is not considered a hotspot of Finnish biotechnology in terms of firm frequency, one might be surprised by the size of the workforce in the region. Lahti is the home of a few old and well-established companies of considerable size, which explains the finding. The same reasoning applies to the Hanko region displaying relatively high employment shares.

[11] Subsidiaries excluded.

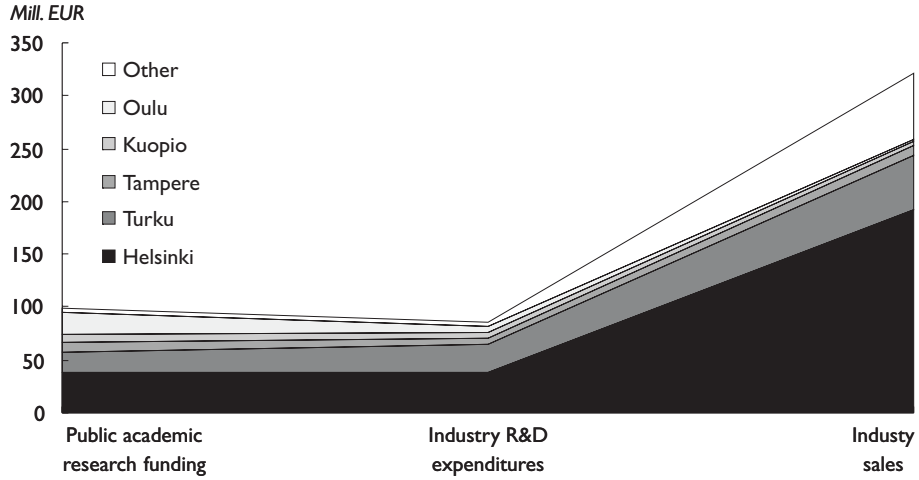

Figure 5.9 Funnel-shaped clitocybe

Figure 5.9 displays the shares of domestic regions of total public R&D expenditures, industry R&D expenditures and industry sales. It gives rise to two possible interpretations of their relationships to each other. According to the first interpretation, one could say the figure displays a continuum, at the beginning of which there is the amount of public money spent on basic research that then in a second phase induces industry led R&D resulting in commercialisation in the last phase. Following this line of interpretation, the Helsinki region has done quite well in transforming publicly financed research first into growing private product development and then succeeding in commercialising the development by conquering close to 60% of markets reached by Finnish biotechnology companies. The relation between public money induced, private R&D generated by that and the sales emerging from R&D is always positive from phase to phase. The Helsinki region seems to create value. [12] Turku is actively transforming publicly financed research into corporate R&D activities but seems to perform less well in commercialising R&D with a share of close to 16% of total sales in the industry. Kuopio and Tampere are similar to Turku, although they display much smaller volumes. Oulu seems to perform poorly as public money flowing rather generously into the region

[12] It has to be stated here that sales figures are a measure of volume, not profitability. Whether companies in the region actually generate net profit is a separate issue not touched on at this point. The focus here is on examining the extent to which the companies in different regions have been able to tap into markets. Sales figures are the appropriate measure for this purpose.

does not lead to industry performed R&D, which in turn is commercialised to an even lesser degree.

Another way of interpreting the figure is to look at it as a cross-section in time. One might say, for example, that the Helsinki region is already in a more mature state having had time to go through all three stages and having set up the necessary down-stream assets and tapped into the markets. Following this interpretation, Oulu might still be in an infant state of development just building up the necessary infrastructure and company base necessary for successful R&D, to say nothing of commercialisation. Given time, the region might then very well create value. Thus, the figure might simply be showing regions in different stages of development and growing towards the markets, as Helsinki has already done.

However, it has to be stated clearly that the data presented in Table 5.9 is unsupportive of the latter avenue of interpretation, as the average age of companies in the Oulu or any other given region does not deviate to a significant extent from the industry average ($p > 0.1$ in t-test). The average age of the companies in other than the five observed regions is the only exception, as it deviates significantly from the overall average age ($p < 0.01$ in t-test). Thus, it seems indeed that there are differences in the performance of single regions when comparing the funding of the regional industries, the employment created thereby and the output the regions have generated.

Table 5.9 Average age of companies by region

Region	N	Average age	Std. Deviation	Min	Max	Skewness	Kurtosis
Helsinki	37	11.3	10	3	57	3.031	11.879
Turku	35	8.5	5.4	2	28	1.504	4.094
Tampere	7	11.1	5.9	5	20	0.656	-1.246
Kuopio	8	11.4	5.3	6	20	0.745	-0.747
Oulu	12	8.8	5	3	16	0.395	-1.663
Other	9	25.3	36.6	5	122	2.895	8.537
All	108	11.3	13	2	122	6.311	50.388

For purposes of checking our results for sensitivity, it is interesting to mirror the outcomes presented above to outcomes based on different sample policies. The exclusion of subsidiary companies from the sample, for instance, has a fairly great influence on the distribution of regions' market shares. To give an example, companies that are part of larger corporations generate in the Helsinki region close to 75% of all sales. In Turku, subsidiaries are responsible for 56% of total sales. The distribution of total SME industry sales shares among the regions changes slightly when only independent companies are included in the analysis. Helsinki still leads with a share of 55% of markets followed by Turku with 26%. Tampere, Kuopio and

Oulu regions contribute 2%, 5% and 1% respectively. Altogether subsidiary companies make 73% of the SME industry sales with a compound 235 million euros in 2003.

5.4.2 Spatial Distribution of Financing

In this final sub-section we look even closer and examine the sources of equity that the companies in the scrutinised regions tap into.

Sales revenues are clearly the most important single source of equity financing in terms of retained earnings for any business that desires to justify its existence in the long-run. A company without sustainable revenues does not create value and is therefore futile. Profits strengthen the balance sheet making a company less dependent on outside financing that often comes with harsh conditions and dilutes the decision- making power of existing owners. Furthermore, internally generated equity is low priced compared to externally supplied equity, because it does not entail any issue or administration costs. Figure 5.10 provides a graphical illustration of the amounts of revenue generated in the regions.

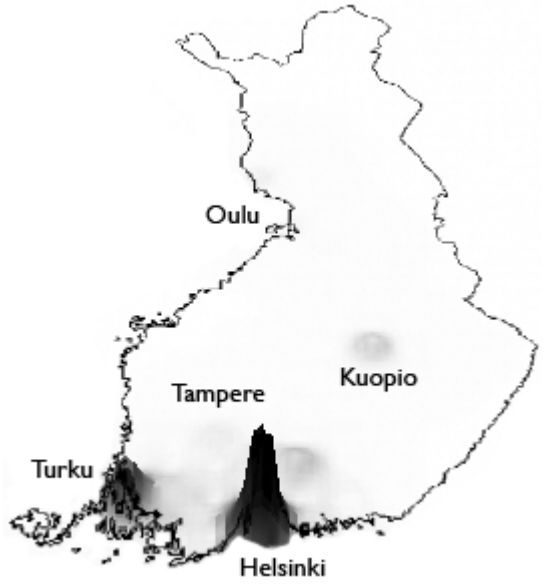

Figure 5.10 Geographical distribution of revenues 2003[13]

[13] Subsidiaries excluded.

Again, the Helsinki and Turku regions account for the bulk of revenues of the industry with Hanko and Vaasa as runners up. The revenue streams of the latter two regions benefit to a great extent from single well-established and mature companies that are well above the industry average in terms of sales. Tampere, Kuopio and Oulu remain far behind in aggregate revenues.

Figure 5.11 shows the sources of external equity incorporating also capital loans that are to be treated as equity on the balance sheet according to Finnish law. Serving as a benchmark, public academic research expenditures are also included in the figure. A striking fact is that the Helsinki region has been able to obtain 45% of all private equity and capital loan financing invested in the Finnish biotechnology SME industry. The Turku region follows with 28%, while other regions share the remainder. The ratio of privately and publicly supplied equity and capital loan financing is also remarkably high in the Helsinki region compared to others. Furthermore, the figure reveals that equity and capital loans invested inthe biotechnology SME industry alone exceed public academic funding of the industry by over 200 million euros.

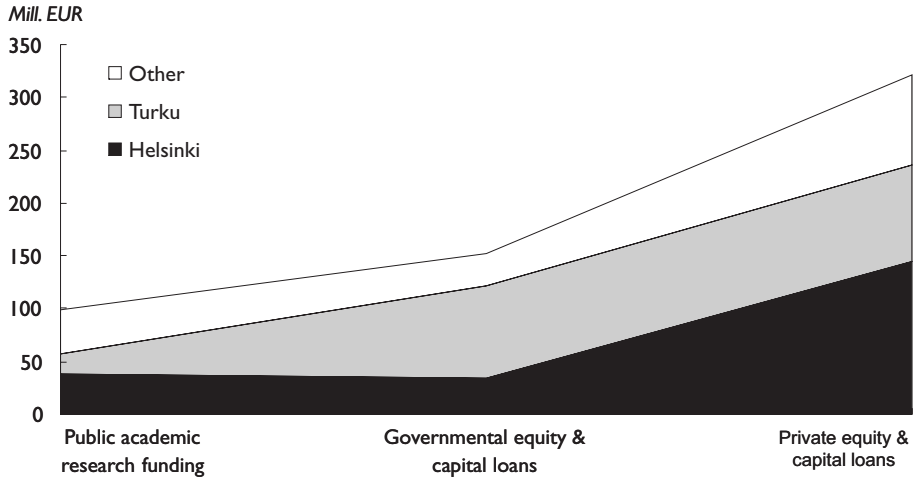

Figure 5.11 Equity & capital loan funding by source and region

In order to avoid misinterpretations, it must be strongly pointed out at this stage that the definition of equity as utilised in this section does not match that on the companies' balance sheets. We have corrected the figures for past losses, because a great part of the industry runs high losses. These would dilute the information on the amount invested equity as they reduce balance sheet equity. Thus, the total amount of equity presented in this section tops the aggregate reported balance sheet equity of companies to a great extent. However, the correction allows us to report the original

amounts of equity invested into the industry and profits earned by the industry, undistorted by losses.

Figure A5.2 in the appendix displays results for a sample excluding all subsidiaries. The Turku region's large share of governmental equity and capital loan funding is striking.

With this said, Table 5.10 presents regional equity financing patterns by source in more detail. The Tampere, Kuopio and Oulu regions are aggregated due to the small frequency of companies in our sample. Single companies would have distorted the picture of the distribution of funding to an extent that results could not have been generalised on a regional level.

Table 5.10 Sources of equity financing by region

Region	Staff	Other individuals	Governm. VC	Priv. VC	Financ. Institutions	Other companies	Other	Total
Finland								
€ (m)	37.3	59.9	47.4	74.7	0.6	126.2	36.3	382.4
%	9.8 %	15.7 %	12.4 %	19.5 %	0.1 %	33.0 %	9.5 %	
Helsinki								
€ (m)	16.7	16.9	6.3	15.8	0.0	111.3	18.7	185.7
%	9.0 %	9.1 %	3.4 %	8.5 %	0.0 %	59.9 %	10.1 %	
Turku								
€ (m)	13.0	12.9	39.5	21.7	0.6	9.1	15.6	112.3
%	11.5 %	11.5 %	35.1 %	19.3 %	0.5 %	8.1 %	13.9 %	
Other								
€ (m)	7.7	30.1	1.7	37.2	0.0	5.8	2.0	84.4
%	9.1 %	35.6 %	2.0 %	44.1 %	0.0 %	6.8 %	2.4 %	

Again, distinct regional patterns are visible. While the industry on a national aggregate level draws on sources in a relatively evenly distributed manner, companies in the Helsinki region have obtained the bulk of equity funding from other companies. This category comprises any companies other than financial institutions and venture capital companies, which are listed in separate categories of their own. The ability to acquire industrial funding can be argued to signal maturity of business or closeness to markets, at least, as investing companies are typically interested in profitable and less risky targets that can be expected to return investments in a reasonable time. Companies in the Helsinki region, therefore, seem to be able to perform under market conditions.

The Turku region, in contrast, gets almost 55 % of equity funding from public and private venture capital institutions, with the public share dominating greatly. Governmental VCs provide more than a third of equity based financing to the region. The region has received and generated 40 % less equity than the Helsinki region. Companies in regions other than Helsinki and Turku are mainly owned by private venture capital companies and individuals.

The total aggregate equity obtained and generated in the Tampere, Kuopio, Oulu regions is 85.5 million euros, 28 % of total equity on an industry

level. Financing the industry in these regions is strongly based on private sources: venture capital institutions and individuals own 44 % and 35 % of the companies, respectively.

Table A5.1 provides results again based on a sample lacking subsidiaries. Again, clear patterns are visible. Independent companies in the Helsinki region are mainly owned by company personnel and outside individuals. Companies in the Turku region receive equity-like financing from governmental sources, while companies in other regions draw mainly on private venture capitalists.

5.5 Conclusions

In this chapter we complement the previously two-dimensional depiction of the geographic distribution of small and medium sized companies in the Finnish biotechnology sector enriching it with a discussion on patterns of R&D collaboration, specialisation, input-output distribution and funding. Based on these presentations we can now characterise each of the five hubs of biotechnology, Helsinki, Turku, Tampere, Kuopio and Oulu, and show their distinct traits in a comparative manner. Such a characterisation, being a cross-section in time, facilitates a rather detailed survey of each region's state of development at the end of 2004. Previously this has been implemented in a more isolated manner, at best, forfeiting setting the individual regions in the comprehensive and comparative industry-level framework or, at worst, in a grossly aggregated manner on a national level that misses the partly large differences in structure and performance of single regions. With this said, we first provide a brief summarising characterisation of each region based on the above analyses before concluding the chapter with their implications on the future development of the regions in the light of the theoretical literature.

Helsinki

The Helsinki region is currently the biggest single hub of small and medium sized biotechnology companies with close to 35 % of the population. Being strong especially in the fields of diagnostics and drug development, the region generated the majority (~ 60%) of revenues of the entire biotechnology SME industry in 2003 with close to 200 million euros. Bioinformatics, enzymes and the agro-forest sectors are potential growth sectors of the future as significant investments have already been made in terms of employment of labour in them.

The Helsinki region is also the most effective in converting public research money into corporate R&D and then further into revenues with total region sales exceeding annual public sector investments and corporate R&D expenditures five-fold. Furthermore, Helsinki constitutes a central hub in the most extensive R&D collaboration network of the industry enabling the absorption and, more importantly from a regional perspective, the dissemination of knowledge to a diversity of partners.

The relatively mature and viable state of the industry in the Helsinki region is strongly reflected in the equity base of the companies. Helsinki-based companies have been able to attract and create (via revenues) close to 50 % of all privately held equity and capital loans of the industry, which in part is rooted in the confidence of investors in the future and performance of companies active in the Helsinki region. Corporate investors, in particular, have been eager to finance activities in the Helsinki region.

Turku

The Turku region is the second largest biotechnology hub in Finland. 32 % of all biotechnology SMEs are located around Turku. It is the most versatile of regions as bioinformatics, drug development, diagnostics, environmental biotechnology, R&D services, enzymes and especially food and feed all seem to be sectors of heightened activity. No other region boasts such a broad sector base. Also R&D collaboration ties to other regions are rather frequent, even if not quite as intense as in the Helsinki region.

However, despite versatility and vigorous collaboration activities the region has been unable to create revenue in the same magnitude as the Helsinki region. The sales of the Turku region constitute 16 % of annual total industry sales with 51 million euros in 2003. Thereby, sector sales exceeded public research funding allocated to the region by close to 300 %, and corporate R&D investments by almost 200 %.

With this said, it is very interesting to see that, again, the commercial performance of businesses echoes in their relative ownership structure. Turku-based companies are primarily owned by governmental venture capitalists, as well as by private VCs to a somewhat lesser degree. According to the leading governmental venture capital institution Sitra, however, to ensure these companies' success necessitates further investments in companies that seem to be still too far from markets to make it on their own. On the other hand, given the investment principles and periods of VCs, the further investments announced might insinuate an expected growth of sales in the very near future. Without rapidly realising earnings, the governmental venture capitalists will remain in a difficult position: do sunk costs matter?

Tampere

Tampere can be argued to be the most characteristic region of all. Although accommodating just above 6 % of all biotechnology SMEs in the country and contributing just below 3 % of total industry sales, the Tampere region has a strong focus on biomaterials and biomaterials alone. One can say that the Tampere region is the only one to really specialise in a certain sector. Similarly, the R&D collaboration network around the region is by far less extensive than those around the previous two regions and is limited to tying in only Helsinki, Turku, Kuopio and Oulu , as there is no collaboration with any of the peripheral regions according to our sample of companies. However, the logic of limited collaboration patterns could be found in specialisation itself: the collaboration might be most fruitful with multifunctional centres.

In terms of performance, the region is capable of generating turnover that exceeded annual corporate R&D investments by almost 60 % with 9.4 million euros in 2003. Still, public basic research funding dominates the figures with 10.7 million euros of public money allocated to the Tampere region for academic research.

The ownership structure of Tampere-based companies suggests potential future opportunities of growth. Most equity and capital loans are provided by private venture capitalists that usually invest only in companies that are already rather close to markets and can, thereby, provide investors with a feasible exit window.

Kuopio

Equivalent to Tampere in terms of the number of companies residing in the region, Kuopio is another region that can be said to be specialised. The Kuopio region is a stronghold for both drug development and diagnostics, which is probably a manifestation of the long and acknowledged local tradition in academic life science research stretching back several decades. Kuopio extends its R&D collaboration network all over the world. There is no collaboration activity between Kuopio and the peripheral domestic regions.

The performance of Kuopio-based companies, however, is not stunning if compared to regional public investments and corporate R&D expenditures. Revenues in 2003 constituted just 55 % of public funding and less than 90 % of corporate investments into R&D. With small volumes and possibly an entrepreneurial attitude towards expanding the business by trusting in one's own capabilities and avoiding external institutional ownership as one potential explanation, and the pure inability to obtain it as an-

other, the ownership structure of Kuopio-based companies is rather difficult to elucidate. Equity is provided to a large extent by individuals either active in business or outside the companies. However, Kuopio is also home to a company, which is publicly listed abroad.

Oulu

The Oulu region, being the third largest hub in terms of company frequency, is in many aspects a case calling for special attention. The first striking fact is that the region is rather diversified compared to its small size. Its focus lies in R&D services, which is admittedly a solid base for generating basic revenue in the short run, but is commonly not regarded as a way of business that will result in exponential growth or breakthrough success, since most returns on the developed product are reaped by the client of these service companies. In the long run, major growth can only be achieved by developing technologies owned by the developer. Furthermore, R&D services can serve to generate revenues that can be redirected into developing one's own products and services. According to the empirical findings above, drug development, biomaterials and the agro-forest sectors seem to be possible fields of application that might provide avenues of growth and future development. As will be discussed further below, however, such a broadly diversified strategy can be theoretically argued to be inappropriate for a peripheral region.

Another aspect that needs to be commented upon relates to the performance of companies in the Oulu region. The region's share of the entire industry's total sales is the lowest among all other regions observed in this study, even though it is the third largest among them in the number of firms. The Oulu region generates only 0.9 % of total industry revenues. This is even more arresting considering Oulu receives over 20 % of total public funding directed towards academic research in Finland. Common sense dictates that intensive basic research should result in heightened corporate R&D activities in the vicinity through knowledge spillovers and interaction between academia and the industry. This in turn should transform into revenues with a certain multiplier. In the case of Oulu, even substantial inputs into academic research are unable to generate incentives for corporate development activities to a level that would exceed public spending. Furthermore, corporate R&D is seemingly less capable of producing sales than in other regions. Possibly too broad diversification can be envisioned to hamper the necessary growth to correct the negative relationship between corporate R&D expenditures and company sales.

Future challenges

We close the chapter by taking a step further back in an attempt to comment on the findings from the perspective of the Geographical Economics literature. The questions that emerge from the present analysis are certainly issues that currently concern technology policy makers facing tough decisions on resource allocation under constant public criticism. Is a dispersed structure of the Finnish biotechnology industry sustainable? How can the existence of more peripheral and smaller regions be justified? How will the structure evolve over time? What are the roles of the two more diversified hubs, Helsinki and Turku, and what are those of the more specialised ones? The theory of Geographical Economics will serve as a basis for deriving potential implications on these issues that the Finnish biotechnology sector is currently facing.

As already discussed earlier, Krugman and Venables (1996) predict that regions will specialise in specific industrial sectors given low trade costs, a high degree of economic integration between regions and a lively intra-industry trade of intermediate inputs of production. Specialised commercial activity will concentrate in a region that offers a solid base of intermediate input producers and end product producers that are specialised in the same sector of the industry, as regional intra-sector externalities between actors specialised in the same trade outweigh the benefits of locating close to final markets in the presence of low trade costs. In the case of the Finnish biotechnology industry, Krugman and Venables's (1996) notion will lead to an industry structure, in which all single regions are specialised in a certain sector of the industry with no two given sectors specialising in the same one. Due to an extreme degree of economic integration and almost non-existent regional differences in trade costs[14] that prevail within the boundaries of a single country, even the most peripheral hubs of the industry can exist profitably while benefiting from regional intra-sector externalities. In other words, such a structure is justified given that all regions specialise in some sector.

Another explanation in defence of a geographically dispersed industry structure is provided by Brezis and Krugman (1997). They argue that the emergence of a new technology, which renders the accumulated technological experience of established older centres irrelevant, creates a situation, in which these established centres will rather stick to the incumbent technology, as they still are more efficient in applying it. New, younger and more

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[14] 90 % of products and services are exported outside Finland.

peripheral centres, on the other hand, will adopt the new technology despite its still undeveloped state, as land rents and wages in these more peripheral centres are lower and compensate for the initially lower returns on the new technology. Given time, the new technology will be developed further in these new centres surpassing the old technology in absolute returns at some point. When this occurs, the younger centres will start attracting human capital from the incumbent established ones, which results in a gradual decay of the older centres.

Brezis and Krugman's (1997) concept justifies the existence of multiple peripheral centres, assuming that every single one of them specialises in the development of a technology with sufficient commercial potential in the future and based on knowledge outside the knowledge base accumulated over time in older and more established centres. In other words, peripheral centres need to be specialised in the development of cutting edge technologies, and, in doing so, be always a step ahead of the larger and established centres to justify their existence and fulfil a purpose that these older centres are unable to accomplish. These pre-conditions clearly set high demands on the innovative and commercial performance of companies in peripheral regions and remind one that their justification is far from self-evident.

It is important to note that both of the above frameworks predict a geographically dispersed structure of an industry with regionally specialised hubs of commercial activity, just as it is observed to be partially the case with the Finnish biotechnology industry. Neither of the models, however, can provide a rationale for the existence, and more importantly, perseverance of larger diversified, non-specialised centres like Turku or Helsinki. Krugman and Venables (1996) predict that diversified centres disperse their activities into specialised centres according to the sectors that those centres are specialised in, while Brezis and Krugman (1997) do not assume the existence of diversified centres in the first place differentiating only between specialised incumbent and emerging centres.

Backed by empirical findings from Feldman and Audretsch (1999), Duranton and Puga (2001) suggest a dynamic model that justifies diversified as well as specialised and more peripheral centres. According to their proposition diversified and large centres are the birthplace of companies that in a first step are able to innovate and learn quickly and efficiently, because of the plethora of different technologies available in a diversified centre through knowledge spillover and other technology transfer mechanisms. Once these start-ups have learnt enough to move to the production stage in their lifecycle they relocate their activities to more peripheral and specialised regions close to other companies based on similar technologies. They do so to avoid the "crowding-out effects" of larger diversi-

fied centres (*e.g.* resource competition, higher wages, elevated rents) and benefit from positive intra-sector externalities that arise when locating in the vicinity of peers basing their activities on a similar, or better, complementary knowledge base.

Thus, Duranton and Puga (2001) see diversified larger centres as creative factories enabling their population to conceptualise innovative technologies based on the multi-disciplinary knowledge base that can be tapped into using various channels, while peripheral and specialised centres are the locations for efficient development, production and marketing of these technologies. In this sense Duranton and Puga (2001) predict a very similar geographic industry structure to that of Krugman and Venables (1996) and Brezis and Krugman (1997) but allow also for the existence of large and diversified centres.

Concluding, we need to ask for the implications that we can infer based on the suggestions of the three theoretical discourses.

Firstly, if Duranton and Puga (2001) is to be taken as a basis for reflection, the more peripheral centres of the Finnish biotechnology industry would be well advised to actively maintain close relationships with the diversified centres in the Turku and Helsinki regions in order to assimilate and benefit from knowledge spawned in those multi-disciplinary centres serving as innovation generators. Thus far, Helsinki region is clearly in the position of a national collaboration hub. As Feldman and Audretsch (1998) conclude in their empirical study, larger diversified centres have a greater propensity to innovate compared to specialised centres. In the spirit of Duranton and Puga (2001), the relocation of post-innovation activities from diversified centres to more specialised ones can be abstracted to symbolise plain technology transfer instead of physical relocation of activities. With this said, the comprehensive R&D collaboration networks existing between the more peripheral centres and both Turku and Helsinki might be a tangible expression of such transfers and speak in favour of the above interpretation.

Secondly, diversified centres need to be aware of their multi-disciplinary environment that is favourable to innovation. Building on the awareness, it is possible to coordinate activities in a way that strengthens this effect and benefits the local population of companies. If nurtured properly, these benefits based on heightened innovation propensity will exceed the crowding-out effects of geographical agglomeration and, thus, justify its sustained existence.

Lastly, it is paramount to more peripheral regions to clearly focus on specific sectors of the industry. Only through specialisation are these regions able to reap the benefits of intra-sector externalities that compensate for the benefits forgone by not locating in more diversified centres. In the case of

biotechnology, probably the most central externalities are represented by knowledge transfers between local academia excelling often in particular areas of science and the industry, as well as among the companies themselves. Without these externalities, peripheral regions gain no advantages over larger diversified centres and can hardly justify their existence. Thus, in the light of this notion, a diversified strategy is not viable for a small peripheral region.

We conclude that given a clear-cut division of roles, the multi-centred structure of the Finnish biotechnology industry is in line with the theory. However, such a division does not currently exist in a satisfactory form and is suggested as a central issue of contemporary technology policy making. More concretely, can we justify the existence of two multi-sectoral hubs and several highly specialised regions? On the one hand, can we expect future success from a regional structure in which Helsinki and Turku act as our multi-sectoral centres and link their activities and resources through intensive collaboration with highly specialised regions, such as Kuopio in the drug development and diagnostics sectors, Tampere in biomaterials, Oulu in academic research, and other regions (*e.g.* Lahti) in enzymes and food and feed applications? On the other, can we justify the recent exiguity of applications based on forestry or the forest industry related potential? These are issues to be solved in regional and innovation policy discussions.

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Appendix 5.1

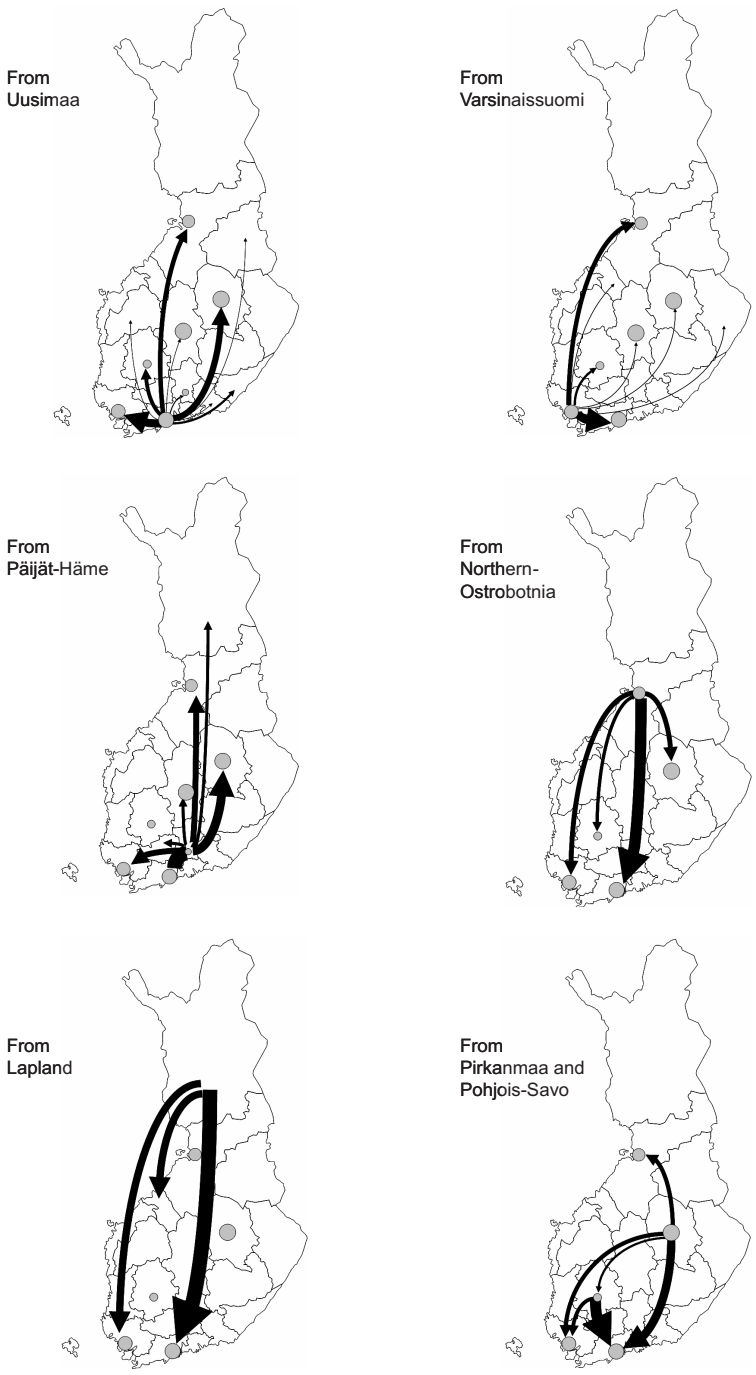

Figure A5.1 Collaboration intensity by region

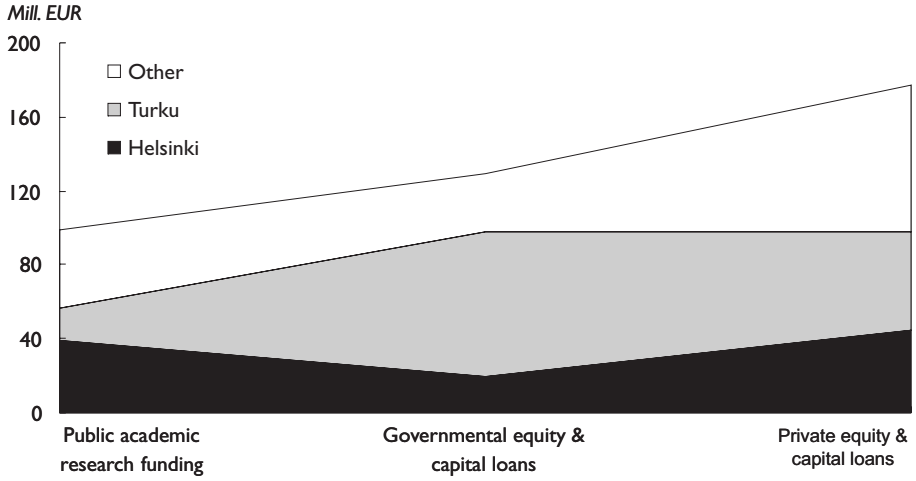

Figure A5.2 Equity and capital loan funding of non-subsidiaries by region

Table A5.1 Distribution of equity financing sources of non-subsidiaries by region

Region	Staff	Other individuals	Governm. VC	Priv. VC	Financ. Institutions	Other companies	Other	Total
Finland								
€ (m)	36.1	56.6	39.0	55.7	0.6	6.8	36.3	231.0
%	15.6 %	24.5 %	16.9 %	24.1 %	0.2 %	3.0 %	15.7 %	100.0 %
Helsinki								0.0
€ (m)	16.6	13.6	6.1	5.2	0.0	0.9	18.7	61.0
%	27.2 %	22.3 %	10.0 %	8.5 %	0.0 %	1.5 %	30.6 %	100.0 %
Turku								
€ (m)	12.1	12.9	31.3	13.3	0.6	4.7	15.6	90.5
%	13.3 %	14.3 %	34.6 %	14.7 %	0.6 %	5.2 %	17.3 %	100.0 %
Other								
€ (m)	7.4	30.1	1.7	37.2	0.0	1.2	2.0	79.6
%	9.3 %	37.8 %	2.1 %	46.7 %	0.0 %	1.6 %	2.5 %	100.0 %

CHAPTER 6

Initiatives on a Sustainable Development Strategy for Finnish Biotechnology

Hermans, Raine – Kulvik, Martti

6 Initiatives on a Sustainable Development Strategy for Finnish Biotechnology

6.1 Introduction

In the preceding chapters we have assessed different aspects of the Finnish biotechnology business using a wide array of methods and tools. This chapter ties together our previous research to form a dynamic framework with its foundations in the international trade literature presented in Chapter 1. Based on the framework we deduce a strategy of sustainable technology development for the Finnish biotechnology sector. We then apply the strategic framework to the Finnish biotechnology industry and identify potential application clusters that project into the future. Finally we introduce six issues that we feel would require thorough discussion among the decision-makers concerned with the Finnish biotechnology sector.[1]

Before discussing the potential solutions, however, we begin our chapter with some general issues.

6.1.1 Thoughts on the Issue of an Ill-Developed Financing System

The thin layer of potential financiers has been regarded as a major problem for Finnish biotechnology companies, striving to move from innovation to commercial applications. In the following we have attempted to evaluate the situation in more depth, with special focus on venture capital -type financing.

Biotechnology is seen as a complicated investment area among venture capitalists, as well as other investors. Recognised problems include the high technological risks, long product development times and especially the risks associated with the "biological component" of biotechnology: unpredictable outcome of development, heavy regulatory environment both in health care as well as areas including genetic modification, potential liability issues, and the complex scientific base yielding only restricted insight for evaluators from outside the field.

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[1] Etla's data base includes highly confidential material on companies' strategies and future prospects, and no single company's data should be identifiable. Consequently, we have focussed on strategic implications for the biotechnology industry and its application areas, marking off company-specific measures. For company specific implications and methods we refer to the topical contribution by Lauriala *et al* (2006).

There is an imminent risk of information asymmetry between investors and investees, and we cannot rule out the possibility that this information asymmetry is sometimes sustained by biotechnology researchers. Several biotechnology company leaders claimed that only biotechnology [research] specialists are competent enough to manage biotechnology companies. The view is in contrast with policies adopted by investors outside Finland.

The lack of investors in Finnish biotechnology companies suggests that the companies are not regarded as sufficiently inviting investment targets. There are no true exit opportunities, nor a developed IPR market; Finnish biotechnology companies seem in part to be isolated from international investment trends. The evident information asymmetry barrier aggravates such isolation, and should thus be broken. (VC-expert 2005)

Investors are reluctant to move alone into a new geographical or contextual area as the costs of screening and monitoring tend to rise. It is critical for Finland to lower the investment threshold by 1) offering the means to diminish such costs and 2) by enhancing the credibility and transparency of the Finnish biotechnology industry.

6.1.2 The Dynamic Framework

In Chapter 1 we constructed a framework based on international trade literature. The concept of comparative advantage inherently influences both business (Attributes 1 and 2 in Figure 6.1) and regional trade strategies (Attributes 1 and 3). Geographical economics stresses the importance of market structure, for example economies of scale, which can be related to the efficient allocation of resources.

A small open economy cannot afford to produce all the products itself, whereas it could gain from the creation of a critical mass in some niche markets. The infant industry argument stresses the importance of subsidising application areas that are incapable of becoming [globally] competitive on their own. The argument, however, stresses the temporary aspect of the subsidies, irrespective of what form the subsidy takes (*e.g.* tax redundancy, R&D subsidy, equity capital financing).

Lastly, we presented the Porterian diamond model including all four attributes (Attributes 1-4 in Figure 6.1). The diamond model was extended to include a dynamic aspect. It starts with unique (regional) factors of production and targets global markets by utilising collaboration with supporting industry and domestic test markets by sequential and clearly communicated business strategies that are in line with their application segments.

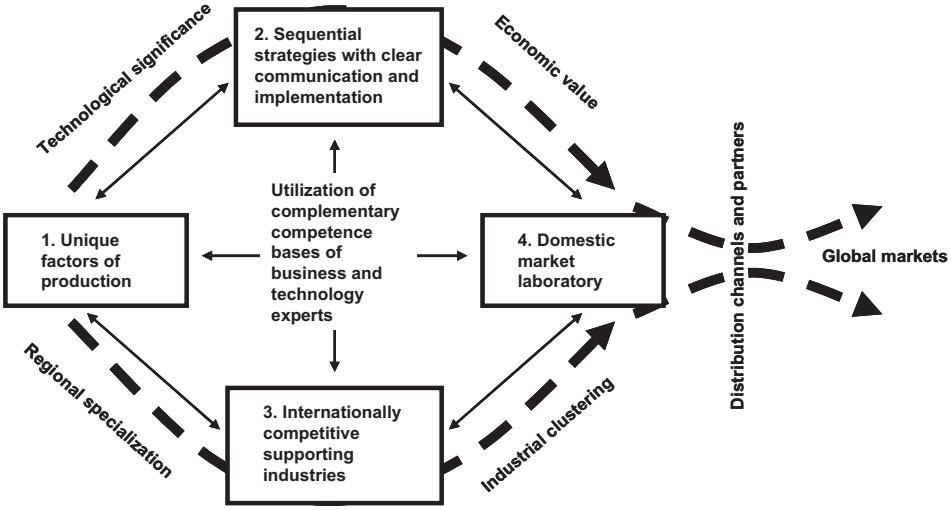

Figure 6.1 Sustainable technology development platform

Chapter 3 presented the SWOT framework based on the opinions of the business leaders of 89 Finnish biotechnology companies; scientific competencies (Attribute 1) are a necessary but insufficient resource to lead to global success in biotechnology business. In contrast to Finland, many European countries and the US have a pool of managers from, for example, the traditional pharmaceutical industry, and venture capitalists with biotechnology expertise have also brought business skills to their portfolio companies.

The biotechnology business leaders called for mechanisms through which business experience from more mature industrial branches (Attribute 3) could be transferred to the new biotechnology companies. In reply, we suggest constituting clusters that target application areas attracting large industrial branches instead of focussing on a specific biotechnology development. If well-established industrial sectors can see potential in new applications offered by biotechnology, the companies could contribute beyond financing, for example, to also support the development of business strategies (Attribute 2) and international distribution channels.

Chapter 4 presented how the Finnish biotechnology companies relate their innovations' technological significance, in terms of backward patent citations, to the company's present value. The analysis indicates that the most technology-oriented companies have the highest expectations for their future sales levels. This finding is supported only in part by empirical studies on foreign markets: studies show a clearly stronger link between forward citations and the economic value of the companies. The link indicates that in-

ternational markets value the companies higher if their protected technological knowledge is referred to by other companies in their patenting activity, suggesting that the technology is appreciated by their counterparts.

This finding can be closely related to Luukkonen's (2005), (Appendix VII) finding describing how companies in distinctive application segments exploit differing organisational forms and, therefore, diverging strategic models (Attribute 2). As also argued in our strategic framework, small infant companies, on one hand, can utilise networks to learn how to develop their products closer to the marketplace even under strict governmental regulation; and companies in mass market business such as energy applications, with a lesser degree of governmental regulation, can on the other hand find vertical integration to be the most efficient organisational form for entering the global market. Expressed in terms of IPRs, companies with several patents in high-technology areas could benefit from a collaborative strategy, whereas firms with a less significant patent portfolio might want to choose a more comprehensive in-house approach for their R&D and marketing efforts.

Chapter 5 argued that regional specialisation patterns matter. If there are regionally specialised unique factors of production (Attribute 1), the region could provide a sufficient critical mass and, consequently a comparative advantage. This should attract external financing and act as a vehicle for industrial clustering (Attribute 3). A well-developed industrial cluster can breed flourishing subcontractor-customer relations and thereby maintain an expert-based and highly sophisticated domestic market laboratory (Attribute 4), a prerequisite on the threshold to global success.

As argued in Chapter 3, many Finnish research-oriented and technologically advanced biotechnology companies lack business expertise. An intensive producer-user relationship could offer the companies a unique opportunity to better understand the needs and requirements of domestic but world-leading customers. By serving the sophisticated domestic customer, companies could accrue marketing experience that can successively be exploited on a larger scale by entering the global markets.

In this chapter we suggest four clusters that are constructed using the strategic framework developed in Chapters 1-5. The identified clusters are:

1. A cluster of drug development and diagnostics based on Finland's unique patient data bases, the applications of which aim at controlling the rising costs of health care.

2. A biomaterials cluster formed around the regional specialisation of Tampere.

3. The cluster for health promoting food applications, which aims at contributing pro-actively to customers' health, and which utilises agricultural applications and by-products from forestry and the forest industry.

4. An energy applications cluster that utilises our abundant forest reserves and leans on the flexible agricultural producers. The long-term goal is to substitute them for the use of fossil fuels.

The identified clusters can also be seen as a proposal for governmentally subsidised programs. At the current developmental stage of the biotechnology industry the "technology programmes" should become clearly focused on distinctive application areas instead of an individual technology or bundle of technologies. This would guide companies to focus on customer needs already at the initial phase of the project.

We will now commence to discuss in more detail each of the four clusters, with special emphasis on sustainable (bio-) technological development in Finland. However, we want to stress that the strategic framework presented in this book is applicable in any country or region considering its opportunities and threats in the international division of labour.

6.2 A Sustainable Development Strategy for Finnish Biotechnology

The threats described in Chapter 1 can best be converted to opportunities by the biotechnology based innovation clusters, inter-linked with each other. **The health care cluster** aims at creating a competitive biotechnology industry designated especially to saving health care costs in the long run. **The cluster for health promoting food** applications could also restrict the increase in health care costs, but is mainly based on its business potential as such.. The success of the cluster is additionally linked to employment within rural areas. **The cluster for energy** applications is closely linked with the geographic skewness of energy production and political implications thereof, as well as the pollution from non-renewable fossil fuels. **The biomaterials cluster** is based on the spatially agglomerated competencies of biomaterials companies within the Tampere region. All application areas face a global competition domestically. Furthermore, the health care cluster and the biomaterials cluster preconceives a global market for their highly specialised products.

6.2.1 Increasing Health Care Costs

The health care domain in Europe is performing a balancing act between the forces of inevitable change. The combination of an ageing population,

an explosion of new therapeutic technologies, and a critical shortage of clinical professionals conflict with the needs to reduce costs, improve overall quality and further expand services. The discovery of previously unknown disease mechanisms and their possible treatments appears to further increase the cost pressures in health care (OECD 2003).

There are several national diseases in Finland, the treatment of which has considerable effects on the Finnish economy. The direct costs of health care constitute only a portion of the total costs as, for example, the impact of absenteeism and pensions can be even more significant from a macroeconomic standpoint.

A profound change is imminent, the signs of which have already been seen in the pharmaceutical industry: a fierce horizontal integration has produced pharmaceutical giants that act in a multinational market, and, however, are sometimes regarded as reaping unethically high profits.

The gap between the public and the private sector has traditionally been wide, but there is already evidence of partial integration, which is probably inevitable in Europe as a whole. The impact on the health care industry remains so far partly obscure, although a clear horizontal integration has recently also occurred among the private health care providers in Finland.

6.2.2 Health Care Applications as a Source of Cost Savings

The potential role of biotechnology is divided. On the one hand, the aging of the population and the medical chances of diagnosing and treating more illnesses than before increase the cost pressures on health care. On the other, biotechnology applications are expected to result in long-term cost savings by, for example, making time-consuming diagnostic methods more efficient and facilitating targeted therapy. Pardes *et al.* have discussed the potential of medical research to control the growth of health care costs, and Hermans and Kulvik have discussed how the Finnish biotechnology industry could offer solutions for the cost crisis in health care while spurring development of an internationally competitive industrial cluster at the same time (Pardes *et al.* 1999, Hermans and Kulvik 2004).

It is noteworthy, that some multinational pharmaceutical companies have stated in their global commercial strategy a clear desire to reduce the overall costs in health care (GlaxoSmithKline 2005, Lilly 2005). Simultaneously, pharmaceutical companies have expressed their specific interest in establishing research co-operation with Finnish biotechnology companies, preferably with the support of the Finnish authorities (Personal communication 2005).

Inaccurate diagnoses or a lack of appropriate treatment easily leads to a prolonged illness and thus an increased use of resources such as personnel and medication. Examples of this are strokes and schizophrenia, with the former being a problem of the elderly population and the latter an illness affecting one percent of the world population. If more efficient ways can be found to diagnose and treat patients who would otherwise need long-term care, even relatively expensive methods can generate considerable cost savings.

The disconnected loop

The public health sector offers services paid for by the authorities but used by patients. Health care costs are covered by taxes paid by everyone, distributed by national authorities, redistributed by hospital authorities, independently re-redistributed by the clinics, and finally consumed mainly by the doctors in charge of the patient, not the patients themselves. The quality offered to patients is mainly disconnected from the local authorities; the payers can express a desire concerning the services offered at a certain price, but the content and true costs are decided mainly by the hospital authorities.

It follows that the system contains virtually no inherent and self-guiding feedback-loops, and only scarce incentives for cost-awareness. Such a set-up is vulnerable to information asymmetry. The need for control can also lead to the establishment of straightforward authoritarian guidelines that do not sufficiently acknowledge the tacit knowledge inherent in the personnel.

Re-establishing a feedback loop

The impact of a new technology can be technical, economical and social. The technical value is usually assessed by medical experts, based on clinical research or best estimation by leading opinion leaders in the field. The economic impacts can be assessed either proactively, for example, by pre-marketing appraisals of the economic impact of a new drug, or retrospectively, for example, by research concerning the effects of an established treatment, performed by health economists at the request of the health care payer. The social impact is projected against general values in society, often even reflected in the laws and statutes of the country. For instance, the model constructed by Kulvik, Linnosmaa and Hermans (2006) combines the different aspects of the impact of a specific technology into one single framework, in which they implemented the model on the impact of thrombolytic therapy in the treatment of strokes, and radiation activated chemotherapy on brain cancer.

6.2.3 The Health Care Cluster

The Finnish Resource Base. The national diseases have to some extent steered the allocation of domestic research resources, which has led to internationally significant areas of expertise in medical science and related fields. Finland's one payer health care system has facilitated a comprehensive patient case record scheme, which, combined with numerous centre of excellence –rated clinical institutes, creates a unique base for biotechnology development carried out in Finland (Eskola 2005). The research knowledge and demand for its commercial applications arising from public health care needs especially related to the aforementioned national diseases enable the domestic market to be used as a commercial test market. Co-operation with end users of health care products promotes the product development of biotechnology companies and the development of service concepts, as well as prepares companies' products and services to enter the highly competitive international markets.

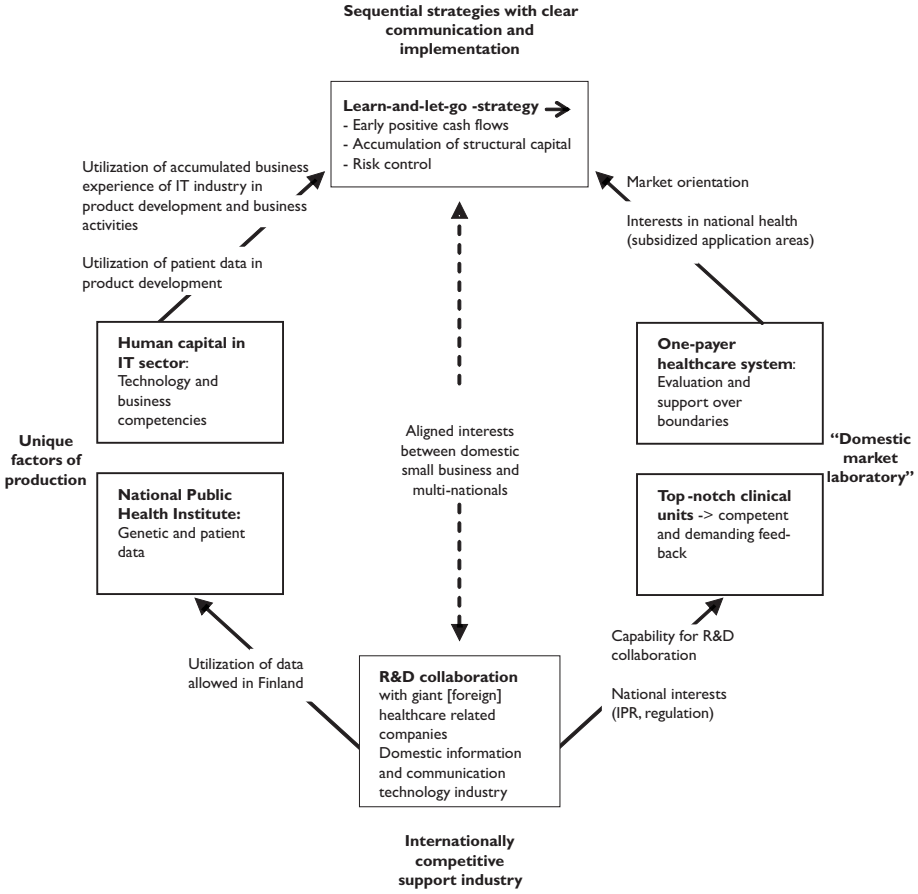

Figure 6.2 The health care cluster

Our suggestion is that[2]:

1. The Finnish data banks at the National Public Health Institute are utilised by offering their content to [international] pharmaceutical companies. However, the data offered is specified to cover only a clearly defined and focused application area. The original data banks remain the property of the National Public Health Institute
2. The research on the data must be performed in Finland, in collaboration with instances controlled by the National Public Health Institute. This would be manifested in legislation as it is in concordance with the original principles and intention of the data bank collection: to promote and enhance the well-being of Finnish citizens. Knowledge spillovers remain the property of the National Public Health Institute.
3. If the data banks and knowledge are as valuable as assumed, even such a controlled opening of their data should attract international pharmaceutical companies to establish research collaboration with Finnish entities. The establishment of a research cluster strongly connected to the international [pharmaceutical] industry would be a strong positive sign for investors, and would also offer a means for reducing the present disadvantageous information asymmetry.

For a discussion on alternative pathways, see Eskola (2005).

We find it critical that the backbone of the research cluster consists of major companies, as they offer the necessary track record and knowledge of successful commercialisation. Even an internationally recognised research institute without an evident track record of commercialisation would not offer significant changes to the present situation *vis-á-vis* investors, risk control and information asymmetry, but it could spur an outflow of innovations and human capital to companies abroad.

The learn-and-let-go strategy

The fully capitalised cost to develop a new drug, including studies conducted after receiving regulatory approval, is estimated at 897 million dollars; only 21.5 % of drugs that begin phase 1 human trials are eventually approved for marketing, and only 3 out of 10 launched products generate after-tax returns (DiMasi, Hansen and Grabowski 2003). These are overwhelming data even for an established biotechnology company. Within the

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[2] The main body of this strategy has been developed in discussions with Professor Juhani Eskola.

Finnish scope it can seem even naive to aim at becoming a full-blown drug development company, that is, to be able to follow through with a product from innovation to market. On the other hand, Finnish pharmaceutical companies have been able to promote some new chemical entities (NECs) from invention to consumer market.

The less regulated sector of biotechnology applications, such as equipment and diagnostic tools, does not have to face an equally long and challenging development process. However, the Finnish market is small and cannot offer a sufficient market potential for specified products. Finland can offer a domestic test laboratory for product development and market testing, but the final product launch must aim at larger initial markets such as the Nordic countries, Germany or France, which requires significant experience and resources.

Both at present and in the near future the vast majority of the Finnish biotechnology companies have to show a clear strategy in order to be credible on the financial markets. Each of the following factors has been identified as obstacles to the credibility of Finnish biotechnology companies or projects (Chapter 3, VC expert 2005):

- preponderance to overemphasise the value of basic research despite an officially disclosed goal of commercialisation
- strong technology orientation
- reluctance to share knowledge concerning the innovation [to investors and evaluators]
- difficulty in accepting skills from outside the sector; typically, the need for specific expertise and experience in the commercialisation process is not acknowledged
- reluctance to accept dilution of a minority position in the company
- overestimation of own managerial skills
- tendency to tamper with the set strategy

Most of these problems are typical for high-technology and research-intensive sectors. However, due to the limited domestic potential, close collaboration with larger players in the field seems to be a necessity; any of the obstacles mentioned discourages successful co-operation.

We encourage Finnish biotechnology companies to consider the dynamic strategy of sequential learning. The main body of the strategy is to develop a product within the company only as long as the required skills are within the core competency of the company. The next phase of development should be realised in collaboration with an experienced company in that field.

The trade-off in a sequential learning strategy is that a dynamic flow of products also places stress on the company through the continuous pressure for change. The additional strain can at least partially be controlled by a well-structured and systematic approach in the execution of the strategy, with knowledge and personnel management becoming critical issues.

The tacit knowledge accumulating through collaboration should be systematically converted into structural knowledge within the company, preparing the company to enter the next phase of development. However, when the product enters the following phase of development, the company should out-license it and focus on the next product – yet developing it one step further within the company based on the knowledge acquired from the previous collaboration. Personnel can be allowed to move with the out-licensed product to the collaborating company, as it results in an extending network of positive collaboration potential.

The aim is to create a dynamic flow of products and, when deemed beneficial, of personnel, while endowing the company with structural knowledge. The sequential out-licensing of products results in an earlier flow of income and a better control of risks inherent in biotechnological development. A concise strategy should also enhance credibility among investors and lead to better terms of outside financing.

6.2.4 The Cluster for Health Promoting Food Applications

The use of functional foods, nutraceuticals and natural health products is clearly gaining in popularity, hand in hand with the growing public interest for increased well-being and prevention of diseases. As, however, the nomenclature is somewhat unclear, we begin with a definition of the terms used.

Definitions

Functional food is defined as a food material that provides a specific functional benefit (health or physiological) in addition to its basic nutritional value. The health benefits are associated with chronic diseases, such as cancer and diseases of the cardiovascular system, not defined as classical deficiency syndromes. The difference is well exemplified in vitamin C, the nutritional benefit of which is in preventing scurvy, but the functional effect is suggested to be in its ability to work as an antioxidant, potentially preventing cancer and coronary heart diseases. Examples of functional food constituents are beta-carotene from, for example, carrots and omega-3 fatty acids from rapeseed oil (canola, *brassica rapa*).

Nutraceuticals are products isolated or purified from foods and generally sold in medicinal forms, such as tablets, capsules or drops. They may have physiological benefits or an ability to reduce the risk of chronic disease beyond basic nutritional functions. Examples of nutraceuticals are fish oils and isoflavones from soy bean.

Natural health products are naturally occurring substances consumed for the purpose of diagnosing, treating or preventing illness or maintaining or promoting health. Examples are products such as amino acids and vitamins extracted from plant, fungal, animal or algal materials, or whole substances derived thereof.

The aforementioned categories are overlapping, and hence we use in this chapter the expression 'health promoting food' as a general term for the concepts of functional foods, nutraceuticals and natural health products.

The demand

The drivers for a food innovation cluster are much the same as for the health care cluster: the health care payer has to find ways to control health care costs. In health care applications, the health care costs are controlled through more efficient treatment modalities, whereas in the health promoting food cluster the goal is set at increasing wellbeing and [as a part thereof] preventing diseases. Measures resulting in prevention or diminishment of the risk of diseases should offer an even more cost-effective way to control the escalating health care costs, assuming that a potentially longer total lifetime *per se* does not significantly affect the absolute amount and severity of diseases.

Preventive medication, such as anti-hypertensive drugs, cholesterol lowering agents and anti-platelet compounds, has become common practise. However, the association between a measurable variable and the risk of a certain disease is complicated to interpret. The relationship between high blood pressure and stroke has been researched for decades, with the health outcomes of more than 0.5 million patients assessed. Yet, the results are still contradictory and continually discussed (Walker *et al.* 1995, Prospective Studies Collaboration 1995, Hansson *et al.* 1998, Ebrahim and Smith 1998, MacMahon, Neal and Rogers 2005). In nutrition both the active components, as well as the measurable variables, can be still more complex.

The assessment of the health outcome of nutritional ingredients typically relies on indirect variables, such as blood pressure and serum cholesterol levels, the effects of which have mostly been assessed in clinical trials where an intervention has been achieved by the administration of a drug. However, extensive studies indicate that the desired eventual end-effect, diminishment of morbidity and mortality, can be more dependent on the type of

the administered drug than the measured indirect variable as such (Lawes *et al.* 2004, Dahlöf *et al.* 2002, Andersson *et al.* 1998). Consequently, a nutritional component's measured impact on one variable, or biomarker, can not directly be translated into quantitatively measured health effects; instead, extensive follow-up trials with the true end-point would be needed to establish the connection and thus, for example economic impact.

Health promoting food is usually not subsidised by authorities, which makes an interesting contrast to most government-approved drugs in Finland: the consumption of health promoting food does not directly affect the publicly-governed health care costs. The challenging task of making reliable health-economic calculations on the benefits of health promoting foods is thus unnecessary from a societal point of view. It is also very unlikely that health promoting food would have a negative effect on public health. Consequently, the rising demand for new health-optimised products as part of healthy living habits can be seen as only beneficial for society.

Consumer attitudes towards healthy food show a steadily rising interest and consumption (ACNielsen 2005, International Food Information Council 2000, International Food Information Council 2002). As the interest in health promoting food seems to span all highly-developed countries, there is a considerable market potential for health products; and the rising prosperity in population-rich countries with significant economic growth can further boost the market-potential of health promoting food.

With an estimated global market in 2002 of $47.6b, and growing, the industry holds clear interests in functional food (Sloan 2002). Besides market growth opportunities as such, the functional food business offers opportunities to reposition everyday products and create added value articles. However, in contrast to most drugs it is probable that health promoting food products must be differentiated locally for each market-segment.

The cluster

In the following we will apply our cluster model step by step to identify crucial attributes for a successful health promoting food innovation cluster.

The health promoting food innovation cluster consists of:

1. Unique factors of production. Similarly to the health care cluster, the unique Finnish patient data banks and microbiological knowledge of the National Public Health institute can be utilised in the research of health promoting foodstuffs (Eskola 2005). Water is available in virtually unlimited amounts and the relatively abundant fields are cultivated by farmers who have shown a significant ability to adapt and survive in the midst of major

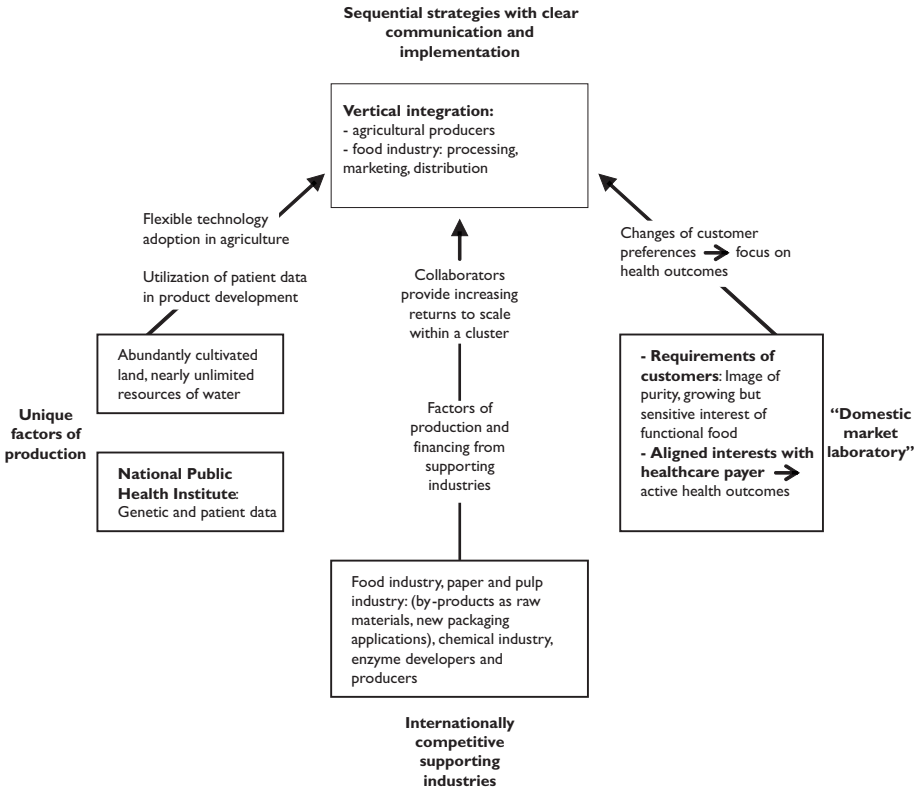

Figure 6.3 The cluster for health promoting food applications

structural changes. The Arctic dimension is a fourth potential factor: an unpolluted soil that requires only minor amounts of fungicides and pesticides, and the exceptionally high concentration of beneficial nutrients in some species due to the extreme light conditions during summer.

2. Sequential strategies with clear communication and implementation. The value creation strategy can largely follow the principles described above in conjunction with health care companies. Products tested in the domestic market laboratory can be exported to global markets in co-operation with international food giants. However, the international strategy should encompass an option of a reasonable termination of the co-operation if the planned sales are not achieved.

3. Internationally competitive supporting industries. Several international food companies have established production in Finland. If the Finnish patient data could be utilised also in the development of health promoting food, yet retaining the original data banks as well as spillover data in Finland through legislative measures, the international companies might

find a co-operation with Finnish companies fruitful. This could also encourage venture capitalists' interest in Finnish biotechnology companies.

4. The domestic market laboratory. Finnish products are perceived as clean, which puts a high standard on all new products entering the Finnish market. Additionally, it is within the interest of the health care payer to promote the health of the population, which aligns the interests, and also partly the criteria, with the development of health care applications.

Health promoting food can be developed either in the form of food additives, or by enhancing the properties of the raw material. We have, however, to face the fact that transgenic plants are under intense debate, and the present customer perception is clearly controversial. This will be discussed further below in the section "Revitalising the Rural Areas under Arctic Conditions". We believe that Finland should proceed in the production of transgenic food only after very careful consideration, where also the trade-off with brand perception is acknowledged.

6.3 Biomass

6.3.1 Pollution and Climate Change

The extensive use of fossil fuels is said to pose a major threat to the global bio-system. We are faced with the fact that several of the global environmental problems will continue to worsen during the next 15 years, irrespective of even the strongest possible countermeasures. Pollution, erosion and global warming are among the most evident changes to be encountered. Furthermore, as oil reserves outside the Middle East are becoming depleted, the rising prices together with a geographically skewed production will probably strain the existing economic balance. However, applications of "green" plant biotechnology and "white" industrial biotechnology could provide some solutions for producing, for example, bio-fuels instead of polluting fossil fuels, as well as growing specified crops that take advantage of the Arctic dimension of the Finnish environment.

6.3.2 Biotechnology as a Tool for Production of Renewable Bio-Fuels

Finland is perceived as a relatively unpolluted country, which could be used to build an image of Finland as being in the forefront of sustainable development. The Finnish plant biotechnological development could focus on plant breeding using non-transgenic solutions. In non-food production, it is possible that the acceptance for technologies dif-

fers from food applications. In biomass production for fuels and other forms of energy, more sophisticated technologies could be used also in the open systems. An example thereof is genetic engineering performed within the same species.

6.3.3 Revitalising the Rural Areas under Arctic Conditions

The anticipated change in climate threatens European agriculture. The following factors have been identified as major concerns:

- shortage of irrigation water combined with an increased need for irrigation
- higher risk of plant diseases and insect attacks
- pollution, toxic compounds in soil

Biotechnology could offer solutions to these imminent threats, and consequently the European Technology Platform has defined goals for the European agricultural research (EC 2004). However, the required characteristics of open-air plants and crops to be grown and developed in Finland differ in many respects from their southern counterparts:

Key goals for agro-biotechnology	Finnish agricultural attributes
improved resistance to drought	virtually infinite reservoirs of fresh water
improved resistance to plant diseases and pests	exceptionally low threat of plant diseases and harmful insects due to cold winters and the geographic isolation (the Arctic dimension; remote geographical location protecting against migration of pests)
improved resistance to toxic compounds in soil	very low pollution in soil, water and air (peripheral location, low population density, sparse heavy industry, and low need for insecticides and herbicides)

Additionally, the Arctic dimension results in specific conditions typical of the Finnish climate, such as a low biodiversity and a delicate balance of species, a low yield of agricultural production which can never be competitive in terms of production volumes, as well as an exceptionally long daytime during the growing season resulting in natural enrichment of beneficial compounds in plants.

It seems inevitable that the mainstream plant biotechnological development will go in a direction not aligned with Finnish needs (EC 2004, European Plant Science Organization 2005, Metzlaff 2005). The mainstream European products probably express characteristics that offer only slight advantages in the Finnish climate. Consequently, the Finnish plant biotechnology research can use the same basic technologies as the mainstream European research, but it must develop applications specific for Arctic conditions. Bioinformatics might strongly contribute to knowledge that enables the breeding of plants that conform to the specific conditions and needs of Finland. Due to the same Arctic dimension, the international market potential of products developed for domestic use does not necessarily lie within Europe.

In food, the research should and could take advantage of the Finnish data banks of the Finnish population. Additionally, it would seem logical to develop food and functional food compounds with positive health outcomes in the fields of common risks in the Finnish population.

Transgenic plants are under intense debate, and the present consumer perception is clearly controversial. Additionally, the risks associated with an Arctic fragile nature could be seen as discouraging open-air cultivation of transgenic plants. Pharmaceutical compounds produced by plant biotechnology, as another extreme, would probably gain consumer acceptability even if produced through transgenic organisms if they are cultivated in closed systems.

6.3.4 The Cluster for Energy Applications

The cluster of energy innovations can draw on the international regulations restricting pollution, while it encourages the public sector to steer the development of energy technology into non-petrochemical solutions. It is also noteworthy that the Finnish refinery industry lacks its own oil reserves; thus, it does not cannibalise on its own funds but is instead encouraged to develop new technologies and conquer new business areas. This is true both for alternative ways of producing liquid fuels, as well as for the utilisation of biomass to manufacture mixtures of polymers that could serve as substitutes for the current plastics.

Forestry and many wood-derived products provide one of the most significant energy resources for a forest-abundant country, such as Finland. As an externality from conventional forestry, there remain many forms of unused residual forest biomass, such as branches, needles, stumps and small-sized trees, which could be utilised as an important resource of energy.

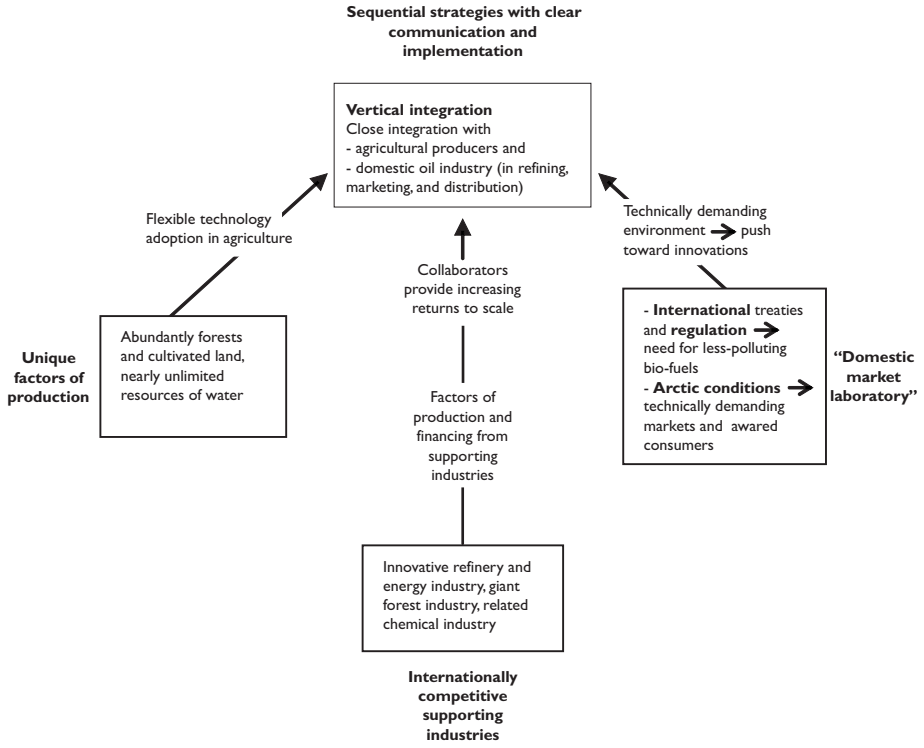

Figure 6.4 The Cluster for energy applications

The cluster for energy applications consists of the following:

1. Unique factors of production. Finland has large forest reserves (70 % of the total area) and relatively large areas of cultivated ground. A climate change might result in a paradoxical situation where the comparative advantage of Finland would be enhanced: growth could become stronger supported by virtually unlimited resources of fresh water and a cold winter killing most of the agricultural pests. Furthermore, Finland's abundant forests provide large and not entirely exploited stocks of energy.

2. Sequential strategies with clear communication and implementation. A clearly defined and communicated strategy forms the mainframe for the successful operation of a biotechnology company. Vertical co-operation with the agricultural producers secures the optimal raw material production, and close co-operation with the distributors enables the full and rapid utilisation of the domestic market laboratory.

3. Internationally competitive supporting industries. The Finnish petrochemical industry has clear incentives to develop solutions offering

alternatives to fossil oil as a raw material. Additionally, the side products from the Finnish forest industry offer several alternatives for energy production, as well as the manufacturing of polymer mixtures.

4. The domestic market laboratory. The Arctic conditions call for fuel solutions that work faultlessly in extreme conditions. These challenging conditions may guarantee the high standards: if the biofuel solutions function properly in the extreme Finnish conditions, they can be expected to work also in the warmer areas with higher market potential.

The energy cluster can offer Finnish agriculture as well as forestry opportunities to adapt to market-based operations. Biotechnological solutions could be applied to enhance the cultivation of raw material suitable for energy applications. Process biotechnology can be utilised in the production of bio-fuels, and the designing and building of large-scale refineries call for co-operation with the domestic machine industry. The Finnish energy innovation cluster could later export the concept as a whole to locations with larger cultivated areas.

6.4 Biomaterials

The biomaterials cluster is clearly based on the regional specialisation (Chapter 5). The resources and outputs of the biotechnology businesses within the Tampere region have focused on the development of biomaterial applications. There have been several breakthroughs related to bio-degradable adhesion systems for ossification applications. There are also some dental applications utilising bio-glass in the Turku region. Whether synergies could be found between the development projects in highly specialised Tampere and the emerging multi-sectoral centre of Turku remains a future issue.

6.4.1 Biomaterials Cluster

The biomaterials innovation cluster consists of:

1. Unique factors of production. Tampere has become the centre for biomaterial related science and R&D. Two nationally significant exits have shown the vitality of this regional cluster, and this vested knowledge serves as a basis for knowledge spillovers to new businesses in the region. Similarly, by binding [local] scientific opinion leaders, for example, to the companies' advisory board and offering them full access to the respective companies' new applications, the opinion leaders' networks can be utilised both for intensive R&D activities and international promotion of the products.

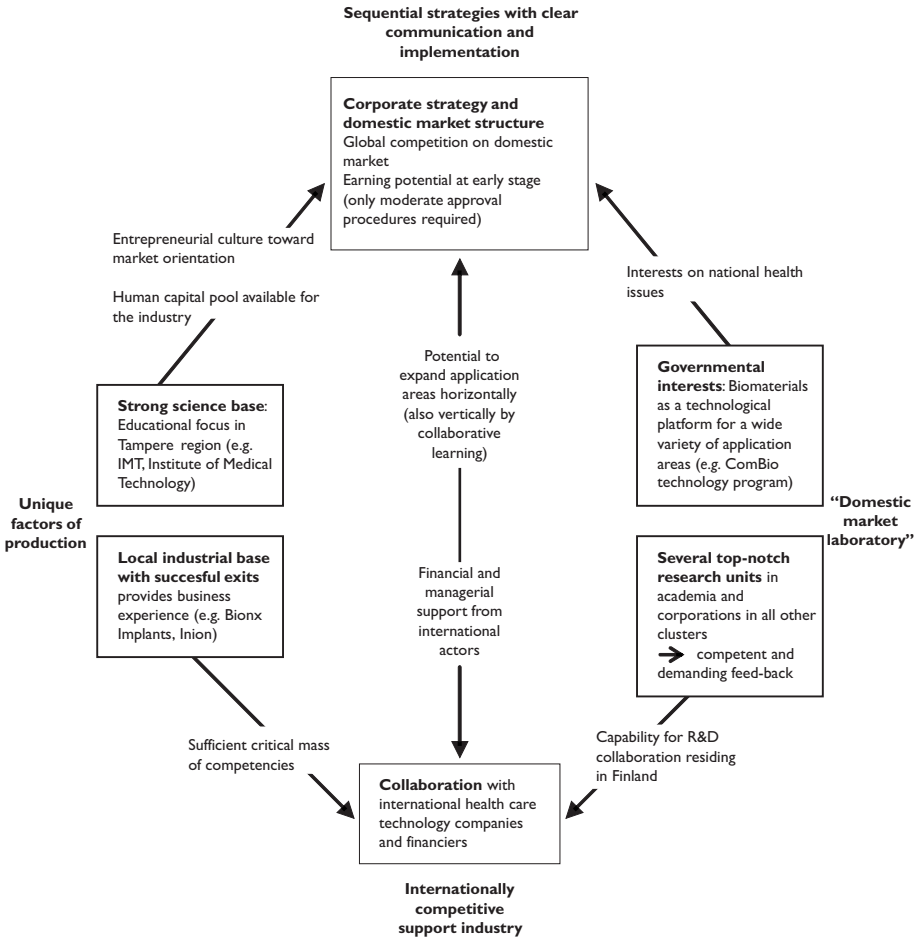

Figure 6.5 The biomaterials cluster

2. Sequential strategies with clear communication and implementation. The value creation strategy can partially follow the principles described above for health care companies. However, the products tested in the domestic market laboratory can be exported to global markets in cooperation with international health care technology giants. Furthermore, despite strict regulation, it takes much less time to get approved than in drug discovery. This enables a product development up to the end-user market. The sequential learning strategy can be implemented in marketing, with collaboration in marketing activities in some specific market area. A successful collaboration can positively impact further R&D activities.

3. Internationally competitive supporting industries. The Tampere region seems to have established possibile exits with international financi-

ers, that is, with other companies or investment institutions. Furthermore, the local knowledge and networks in electronics and software programming can be utilised in biomaterial related projects. Life sciences could provide many application areas that could be attractive in the eyes of related industries.

There seems to be a lack of domestic industrial fields that would have a resource-based or market-oriented close link with the development of biomaterial applications. This could imply that the most promising companies might eventually be taken over by multinational companies active in the application area. However, if the local cluster holds a critical mass it could provide tempting technology transfer opportunities and an attractive labour pool for the incoming foreign owner. In such a case there would be a clear incentive for the acquiring company to preserve the smaller [Finnish] company (Haspeslagh and Jemison 1991). The strong locally specialised industrial setting could thus help in acquiring foreign financing.

4. The domestic market laboratory. Biomaterials have been one of the major technological focus areas of the Finnish innovation system. As a result thereof, the institutions involved have gained both technological and financial knowledge. The state support has also strongly emphasised cooperation with the university hospital clinical units, and hence the actors face well-educated and challenging customers also locally. In addition to market testing, the collaboration with domestic top-notch clinics and university hospitals could provide some opportunities to find new application areas for biomaterials; a close contact with domestic customers enables companies to understand the customer needs.

6.5 Solid Basis on Distinctive Innovation Clusters: Bioinformatics

6.5.1 The Role of Bioinformatics in Finnish Health Care

It is in the best interests of Finland to both use the data banks, and yet protect them from exploitation in an unrefined, low-value form. The value creation potential is best captured by processing the data as far as possible domestically. Bioinformatics in its wide definition is the backbone of the value creation path; sequence analysis, genome annotation, gene and protein expression analysis, structure prediction and biological system modelling range from core DNA to the complex cellular subsystems (see also Eskola 2005).

Finland clearly has a relatively strong IT industry, and there are several research groups and companies that have been able build up significant knowledge in the field of bioinformatics, spurred by the top-notch gene research that requires efficient computational skills.

Processing the data banks domestically offers a means of protecting the data, as only the results of the data mining are delivered to the customers. The valuable raw data, as well as the valuable information processing data, remain the property of domestic entities. Through such an arrangement, the National Public Health Institute, the respective research institutes, universities and hospitals can refine their data and thus create value both in the form of more valuable end products and the spillover data that can be utilised for further Finnish research.

The bioinformatics companies gain from being able to not only sell top-notch processing ability, but also offer results based on proprietary data; this can result in an absolute competitive advantage. The companies can create high-value but well-protected data processing tools in close co-operation with the National Public Health Institute and research teams, offering an excellent R&D potential. Additionally, the potential is created for a dynamic flow of people from research teams to bioinformatics companies, as well as for a possible exit of bioinformatics professionals to companies that utilise the data analysed.

From a national and technological standpoint, it could be logical to strongly promote an existing and well-developed IT industry to proceed to new application areas. Due to the domestically controlled data banks, the companies could be tied to Finland, in contrast to potential biotechnology companies that seldom build on proprietary knowledge that can not be easily transferred abroad.

For the National Public Health Institute, a well-controlled utilisation of the data banks would yield the highest possible value creation; a utilisation that offers an accumulation of new data based on the processing of existing data banks. The National Public Health Institute can guide the utilisation of the patient data banks with emphasis on positive health outcomes on a national level.

For society, the setup offers a chance to steer support to domains aligned with the national health aspect, with the ultimate goal of promoting the wellbeing of its citizens and control the growth of health care costs. In the long term, the created cluster offers a natural way to increase co-operation with multinational pharmaceutical companies in projects that are in Finland's interests.

6.5.2 Bioinformatics as a Technology Platform

The key to understanding the functions of cells and biological systems lies in a better understanding of their genetics. With the development of high throughput sequencing equipment, the collection of data has expanded exponentially. Bioinformatics has developed to extract knowledge out of the massive data collections.

The basic principles and challenges for data refinement are strikingly similar within all fields of biotechnology, and thus most of the points described in section 6.5.1 also apply to other application areas of biotechnology. We simply conclude that bioinformatics could form the basis for a successful technology platform for and within Finnish biotechnology as a whole.

6.6 Conclusions

Below we present six central policy implications open to discussion:

1. Biotechnology in parallel with other technologies in public sector technology programmes. In order to ensure that technologically advanced projects reach their economic potential, the public sector should organise their technology programmes with the primary aim of developing specific industrial application areas or processes instead of a sole commitment to a certain technology field. The central issue is to guide the technology development projects to meet the needs of the market place. Accordingly, the technology programme on energy applications, for example, might subsidise research and development also in potential technological fields of conventional physical and more modern biological technology, not solely in biotechnologies. The biotechnology development should be mirrored and compared against presently dominant technologies in the production and utilisation of the specific application. If, and only if, a new technology offers clear advantages to the existing technology, the new technology should be strongly [but temporarily] supported.

2. Bioinformatics as a basis for the distinctive application areas. Utilising the Finnish population and patient databases would necessitate a strong development of the Finnish bioinformatics research and industrial activities. Furthermore, there are many application areas within plant and industrial biotechnologies. The accumulated competencies in the Finnish information and communication technology (ICT) sector provide a strong resource that could be exploited in the field of biotechnology. The creation of commercial applications in bioinformatics might bring together highly competent business experts of the Finnish ICT sector, venture capitalists and the biotechnology industry.

3. Public sector promoting R&D programmes: emphasising sustainable development. R&D projects of the biotechnology companies are aimed at increasing the owners' wealth. Sustainable development, which is focused on long-term perspectives, does not necessarily provide any incentives for the leaders of a company. The public sector could be a sole actor steering the company's R&D activities to such application areas, which are aligned with the strategic aims of the public sector related to sustainable development. Society could define how much it would be willing to pay for the promotion of sustainable development, and the biotechnology companies could assess the opportunity costs of the societal goals with the terms of financing from the private sector.

4. Public sector subsidising start-up companies: the customer approach. The public sector can set economically meaningful policy goals, which support sustainable development. As an example, the public sector can pursue restrictions on the increase of health care costs. Accordingly, a public sector financier should demand the same goals from the project that it subsidises; the public sector acts as a customer. Such behaviour would also steer the subsidised start-up company to consider the customer benefits. This requires the company to place special emphasis on pricing the product, and to communicate the cost-benefit ratio in measurable terms. The latter creates a basis for a solid valuation of the company. Thus, the public sector's role as a customer advances the accumulation of business attitude and competencies within the company.

5. Public sector financing biotechnology companies: the venture capital approach. The financing body of the public sector can provide external market-based financing for the companies at a more matured stage. In order to avoid serious market disturbances, the finance terms should be comparable to those of a private venture capitalist. Conventional milestones are set according to the strategy of the biotechnology company. If the R&D activities and the commercialisation do not proceed according to set milestones, the governmental venture capitalist performs a sanction; the project can be cancelled, the related IPRs can be realised or the ownership of the company can be transferred to another party. The failure of a publicly funded project should, however, produce some spill-over effects to other commercialising organisations in society, as opposed to privately funded projects. In all cases it is imperative that both parties have a clear incentive to act as transparently as possible, with clearly defined upside and downside risks.

6. The creation of globally competitive clusters. The biotechnology sector would benefit from the formation of clusters built on domestically

abundant but globally relatively scarce resources that are regionally identified as critical masses. These clusters should be based on:

a. Unique factors of production
b. A domestic market laboratory
c. An internationally competitive supporting industry
d. A clearly communicated and well exercised sequential strategy.

The public sector can, for a limited period, boost such parts of an industrial cluster that are identified as being critical elements for long-term economic growth. We identified four clusters. This is however not an exhaustive list, and the identified clusters are, for example, pending on legislation and preferences of the public sector.

Closing remarks

The development of biotechnologies should not contain any intrinsic value *per se*. The commercial value of the biotechnology could be benchmarked with the value of alternative technologies; and consequently, biotechnology could become part of the technology options for companies active in established and conventional industries.

The efforts in Finland have created a strong domestic biotechnology industry base. In the following step the key issue is to capture highest possible value from the efforts expended. We hope that the tools and forecasting methods applied and developed in this book and the appended related articles, could build a justified pathway for further discussion and measures.

The developed tools could favourably be used in other high technology sectors at an infant commercialisation stage as well. To that end, the valuable experience gained from the creation of the Finnish biotechnology industry could be utilised even more pro-actively when considering prospective technological leaps.

Nanotechnology has been described as the next paradigm shift in technology. Being both highly technological in nature as well as generic by definition, it bears clear resemblance with the expectations put on biotechnology 1-2 decades earlier. Consequently, it could be fruitful to extend the presented methods and analyses to the context of nanotechnologies. This should be done in the near future, while the sector is still in its infant stage, at present an estimated 15 years behind biotechnologies in terms of commercial applications. The presented strategic framework, based on international trade literature could provide a solid basis for innovation policy and business activity in the small and open Finnish economy – before dedicating to major investments.

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Appendix 1. International Mega-trends and Growth Prospects of the Finnish Biotechnology Industry

Hermans, R. – Kulvik, M. – Ylä-Anttila, P. (2005). International Mega-trends and Growth Prospects of the Finnish Biotechnology Industry: Recent Economic Research and Policy Implications. *Journal of Commercial Biotechnology*, vol. 11, no. 2, 134-145.

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International mega-trends and growth prospects of the Finnish biotechnology industry: Recent economic research and policy implications

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Abstract

The aim of this paper is to describe recent economic growth forecasts of the Finnish biotechnology industry and provide analysis of the international and industry-specific factors behind these forecasts. The new economic geography of the European regions suggests that spatial agglomeration of economic activities will be strengthened internationally if European integration deepens. In addition to that, the Finnish pharmaceutical industry has enjoyed high regulatory protection and it has achieved similar price mark-ups during the 1970s–1990s to its counterpart in the USA. According to the analysis of small and medium-sized Finnish biotechnology companies, it seems that the most promising biotechnology companies have a well-balanced combination of intellectual capital. Despite expectations of rapid growth, it will take decades rather than years for the biotechnology industry to catch up with the three industrial pillars, the forestry, machinery and electronics industries. To fulfil the expectations, there is a need to build collaboration and financing networks between the biotechnology industry and traditional industries, such as forestry, electronics and pharmaceuticals. Most of the current Finnish biotechnology companies are related to healthcare activities. The Finnish biotechnology industry could offer solutions to the cost crisis in healthcare while at the same time spurring development of an internationally competitive industrial cluster.

Keywords: *spatial agglomeration, price–cost margins, capital structure, intangible assets, input–output analysis*

INTRODUCTION

Background and objectives

The objective of this paper is to present an overview of and policy implications on the international mega-trends and the growth prospects of the biotechnology industry in Finland (see Hermans[1]). The present paper analyses Finland's biotechnology industry from the five viewpoints of international and regional integration,[2] the market structure of the pharmaceutical industry,[3] capital and ownership structures of bio-pharmaceutical companies[4,5] as well as companies' intangible assets and growth expectations[6] and discusses the results of a forecasting model based on the companies' growth expectations and the probability of their success.[7]

An overview of the innovation policy of Finland from the perspective of the biotechnology industry is given first. The biotechnology industry plays a special role in Finnish growth and innovation policy. This special role has shaped the questions addressed in these five studies and the way in which the research was carried out.

Because biotechnology has played a significant role in Finnish innovation policy, certain conclusions are drawn regarding each of the five research areas, both from the viewpoint of firms'

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Out of a total 120 Finnish bitechnology companies, 84 participated in the survey

strategies as well as business and innovation policy. Hermans and Kulvik[7] discuss the potential of the biotechnology industry to grow into one of Finland's main manufacturing industries or growth clusters, comparing it with the healthcare sector, and the forestry, machinery and electronic industries. (See also Hermans and Ylä-Anttila.[8])

Definitions

The biotechnology industry does not exist as an individual branch in any official statistical classification. A single definition was agreed upon at an Organization for Economic Cooperation and Development (OECD) ad hoc meeting held in Finland in May 2002. According to the definition, biotechnology is: '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.' In addition, a list-based definition specifies biotechnology processes in more detail.

Companies can develop biotechnology processes or they can apply biotechnology processes in their production. The former can be called biotechnology research companies and the latter biotechnology-using firms. An individual company can be classified as belonging simultaneously to both categories. In this case the company can be called an integrated firm (see Nilsson[9]).

The research behind the present study employs the biotechnology-related data drawn from the ETLA (the Research Institute of the Finnish Economy) survey. The ETLA survey was conducted at the beginning of 2002 and covers 84 companies. The first descriptive analysis of the ETLA biotechnology survey was carried out by Hermans and Luukkonen.[10] There were approximately 120 biotechnology companies in Finland at the end of 2001. Thus, the coverage of the data seems sufficient. The problem of how to define biotechnology companies was solved by choosing the firms in the database of the Finnish Bioindustries Federation to represent the population of Finnish biotechnology companies.

The Finnish Bioindustries Federation classified its member companies into seven categories. In the ETLA survey an individual company could classify itself simultaneously in several categories. Figure 1 depicts in which categories the biotechnology companies consider themselves to be. Most of the companies are involved in the businesses of pharmaceuticals and diagnostics.

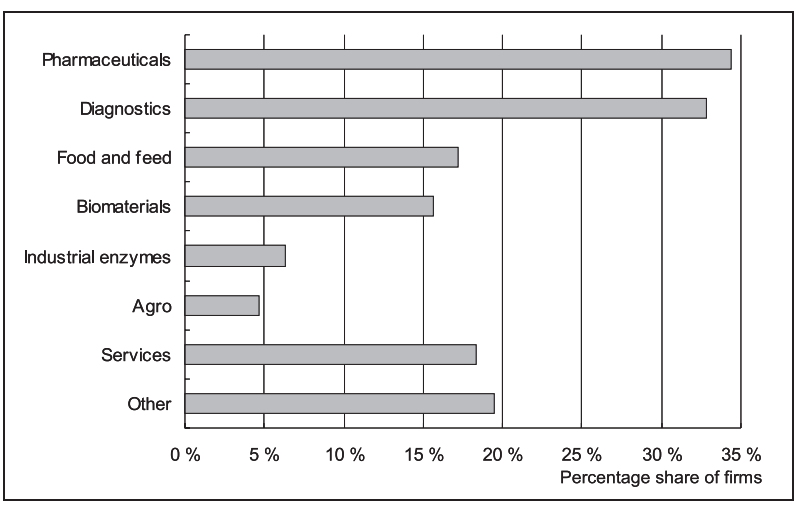

Figure 1: Activities of the biotechnology companies in the ETLA survey by sector

INNOVATION SYSTEM AND CURRENT STATE OF THE BIOTECHNOLOGY INDUSTRY

The following discussion on the current situation of the Finnish innovation system is partially based on Hermans and Ylä-Anttila research.[8] During the 1990s there was a clear shift of emphasis in innovation and industrial policies. While policies in the 1980s can be characterised by picking the winner's approach, policies adopted in the 1990s can be described as providing or enabling policies. The emphasis moved towards indirect measures in influencing firm behaviour, avoiding direct interventions in the product market, promoting competition, and providing a stable macroeconomic environment. In 1990 the concept of a national innovation

Industrial policy in Finland changed from the 1980s steering to 1990s supporting measures

system as a basic category of science and technology policy was introduced to accentuate the systemic nature of innovation.

The roots of Finland's current innovation policy date back to the 1970s and 1980s, when the decisions to increase science and technological investment were made. For more on the background and development of science and technology policy, see Lemola,[11] Georghiou *et al.*[12] and Ylä-Anttila and Lemola.[13] The basic pillars of research policy were built partly in the 1960s, but mostly in the 1970s and 1980s and the first programmes for applied research were started. The goal was to lift the technological level of Finnish industries and to reduce the dependence on raw material-driven production and exports. The one-sided structure of exports was regarded as a problem – the intermittent problems with deep imbalances in the economy were due largely to strong cyclical fluctuations in the export industry.

Heavy investments in ICT

Even at the end of the 1970s Finland's research and development (R&D) expenditure relative to gross domestic product (GDP) was one of the lowest in the industrialised countries. The 1980s was a decade for systematic and goal-oriented technology policy. One of the key vehicles for implementing this policy was the National Technology Agency of Finland, Tekes, established in 1983. Regional science parks and technological centres were established to support the dissemination of research findings and utilisation of regionally generated information. The R&D expenditure grew in real terms at a rate of about 10 per cent per annum, which was one of the fastest in the OECD countries.

The main tools for implementing technology policy were technology programmes, which fostered the implementation of a strategic innovation policy, thus making use of the small country's scarce resources. According to this policy, heavy investments were made in information and communication technology (ICT) in several technology programmes that had been initiated before the founding of Tekes. The huge success of Nokia and the ICT cluster that emerged around it was a sign of the successful policy choice, even though the policy naturally accounted for only part of the success.[14]

The 1990s can be called a decade of the national innovations system

The 1990s can be called a decade of the national innovation system in terms of innovation of science and technology policy. Innovation activities started to be seen more and more as a key product of dialogue and interaction between different actors – companies, research institutes, financiers of innovative activities and other policy makers.

The structural change that occurred in the Finnish economy in the 1990s was relatively swift from an international perspective as well as relative to Finland's own economic history. The transformation toward a competence-driven economy had continued for several decades already, but it accelerated considerably in the 1990s and strengthened the structural change. Technology policy played an important role even though most of the development was company driven.[13] Economic integration and the opening of the economy to international competition spawned a competence-driven phase of growth. The innovation intensive sectors benefited more than other sectors from the new markets. Productivity and capital efficiency increased considerably.

Changes in technology and business policy and innovation policy inevitably have an impact also on the biotechnology sector. The impacts are clearly apparent in at least two respects. First, since it was possible to use policy to foster the success of the ICT sector, it was deemed possible to do the same thing in the biotechnology sector. The R&D investments of the companies in the ICT sector – mainly Nokia – rose sharply in the 1990s and the early 2000s.[15] As regards research activities Finland has specialised more in the ICT sector than any other country in the world. Public investment was

Could the ICT policy success be repeated in biotechnology?

especially important in the 1980s and 1990s during the recession. By the end of the decade, research activity became more company-oriented, even though the ICT sector's share of public research funds was still substantial. Public investment in the ICT sector had spawned a considerable increase in private investment: the ICT sector seemed to be an example of a successful strategy of innovation policy, so it could be worthwhile to search for another sector with new potential – biotechnology.

Secondly, the founding of regional competence centres has had a positive impact on the biotechnology sector and on investment in companies in this sector. Most of the companies in this sector are located in five of the science and technology parks located around Finland (see Figure 2). From the standpoint of the biotechnology and bioresearch, the situation is problematic: it is difficult to find a sufficient critical mass. Furthermore, Kafatos *et al.*[16] pointed out that there is little cooperation between the regional biotechnology centres in Finland.

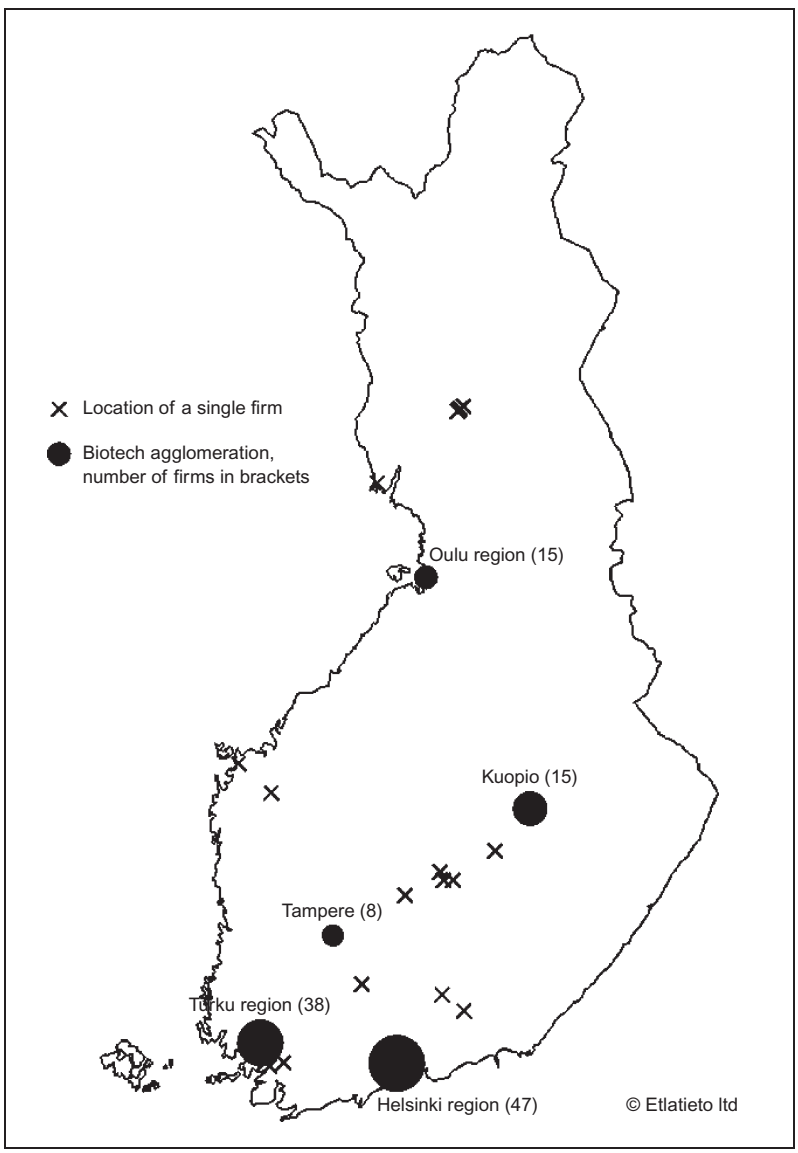

Figure 2: Location of the Finnish biotechnology companies in 2003

The differences between the biotechnology and ICT sectors from the standpoint of the functioning of the innovation system and technology policy are significant, as Luukkonen and Palmberg[17] demonstrate. Biotechnology is not closely affiliated with existing sectors that are currently strong in Finland – the sector has no strong manufacturers or growth engines. The Finnish biotechnology sector has concentrated – as in several other countries – on biopharmaceuticals. The significance of the pharmaceutical sector in Finland's industrial structure has nevertheless been relatively small compared with many other countries. There is relatively little biotechnology research and manufacturing activity related to the large traditional processing industries, such as the forest and chemical industry.

The research and manufacturing activity related to biomedicine – or biotechnology in general – has been chosen as a focal point of business and technology policy in almost all developed countries. Competition in the sector is thus keen and demands high investments. The risks related to the public financing of innovation policy and biotechnology are great.

Finland's biotechnology sector is currently quite small. In 2001 the value added by the entire biotechnology sector was about €500m (Table 1). This figure includes an estimate for biotechnology-related production of large multi-sector enterprises. The total value added of small and medium-sized biotechnology enterprises was less than €100m in 2001.

Table 1: Biotechnology industry in Finnish enterprise sector

	Biotechnology industry SMEs (€m)	Total biotechnology industry* (incl. multi-sector firms) (€m)	Total enterprise sector (€m)	Biotechnology industry's share of enterprise sector – SMEs (%)	Total biotechnology industry's share of enterprise sector* (incl. multi-sector firms) (%)
Number of companies	110	130	225,000	0.05	0.06
Sales revenues	200	1,400	272,000	0.1	0.5
Value added	90	500	88,000	0.1	0.6
Employees	2,000	14,000	1,319,000	0.2	1.1
Exports	120	600	54,000	0.2	1.1
R&D expenditures	162	300	3,300	4.9	9.1

Total value added for the biotechnology sector in 2001 was €500m

* Sales revenues and exports of multi-sector companies are estimated for biotechnology production and employment and for employment as a whole.
Sales revenues, value added, exports and R&D expenditures are based on figures provided by enterprises regarding extent of biotechnology activities.
Source: Based on data for 2001 (ETLA, Statistics Finland).

The situation of the biotechnology industry is illustrated by the fact that the R&D expenditures of the small and medium-sized enterprises (SMEs) are considerably higher (approximately 40 per cent) than their value added. The research investments have for the time being generated very little production. The research investments of SMEs are funded primarily by the government. Since the public financing of the biotechnology sector's research has been about €400m since the beginning of the 1990s (Figure 3), the average financing per SME has been €3–4m. This sum includes both direct funding to the SMEs and also funding to universities and research institutions that companies can utilise indirectly.

Even though public financing has not

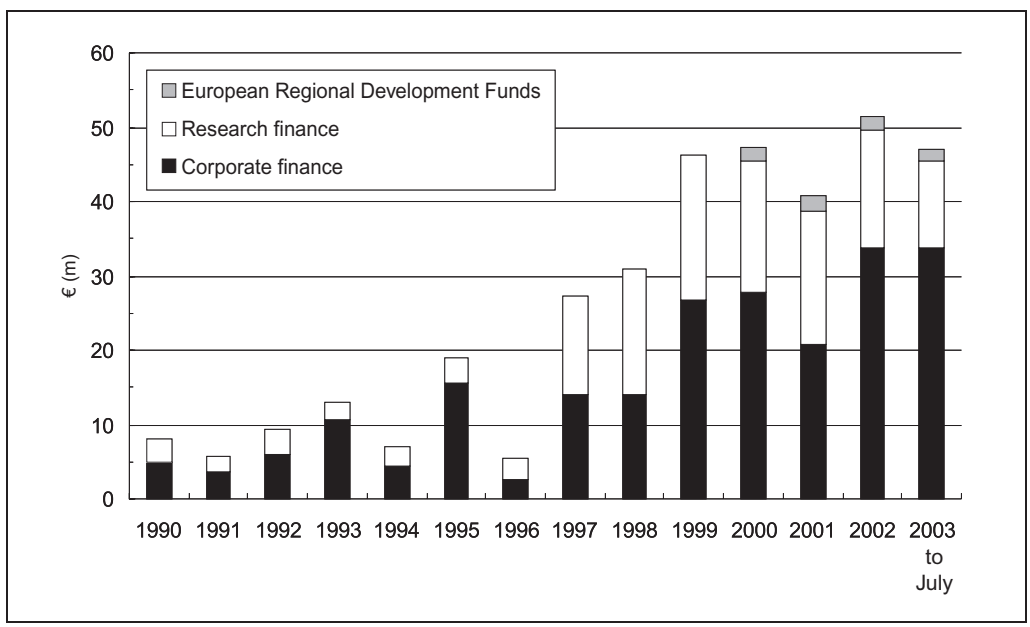

Figure 3: Biotechnology-related funding from Tekes, the National Technology Agency of Finland, 1990–2003 (€m in 2002 prices)

been comparatively high, relative to the size of the economy and the number of active enterprises it has been of significant magnitude.

GROWTH PROSPECTS OF BIOTECHNOLOGY SECTOR

Forecast growth and other sectors

A growth forecast combining companies' sales forecast, current sales revenues and the bankruptcy risk

Hermans and Kulvik[7] compiled an economic growth forecast where the probability distribution is formed from the companies' sales growth forecast and their current sales revenues. The model also incorporates the bankruptcy risk. The modelling technique is based on the sectoral input–output method utilising the purchase and sales volumes announced by companies in the respective sectors.

In year 2006 a forecast value added €850–1200m, corresponding to an annual growth of 10–18 per cent

According to the forecast model based on the data from the year 2001, the biotechnology cluster is able to produce €850–1200m worth of value added with a probability of 90 per cent in the year 2006. In the year 2001 the entire biotechnology sector's value added was about €500m, meaning that annual growth of the entire cluster would be 10–18 per cent. Despite this, the value added will remain relatively low because the biotechnology companies use a high amount of funds for purchasing services and goods from outside the firm. According to the forecasting model, by 2006 the biotechnology cluster's contribution to annual GDP growth will be about 0.05–0.09 percentage points.

The forestry, machinery and electronics industries are the three main pillars of the Finnish economy

In order to put the growth possibilities of the biotechnology sector into perspective, we can ask when Finland's currently strong sectors – the forestry, machinery and electronics industries – were in the same situation (Figure 4). The forecast growth of the Finnish biotechnology industry is not strictly comparable with the forestry, machinery or electronics industries. There are obviously many differences in the necessity of international collaboration in research and in business. However, it is interesting to see how long it has taken, in these mature industrial sectors, to grow to the position where they are today. This can be contrasted to the Finnish biotech industry.

In year 2000 prices, the value of forest industry production was €0.5bn in the early 1950s. The electronics industry reached that level in the mid-1970s. If the biotechnology sector achieved the same growth as that of the electronics industry fuelled by Nokia, it would reach the position of the 'fourth pillar' of industry in about 30 years. If the life cycle of the biotechnology industry as an independent

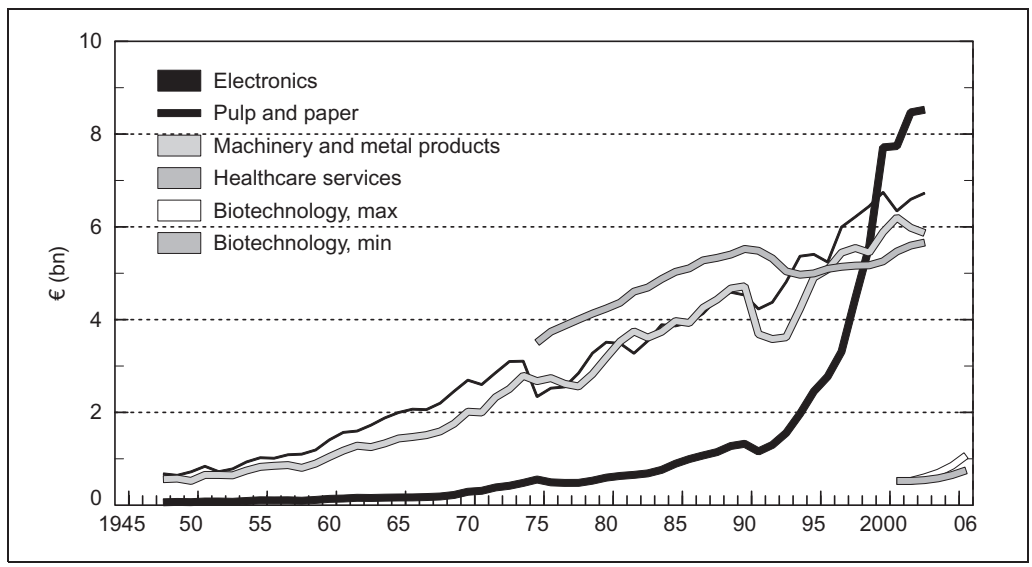

Figure 4: Production by sector 1970–2002 (€bn in 2000 prices)[18]

For the main pillars it took 25–50 years to reach their present position, for biotechnology sector it would take 15–30 years

sector is comparable to that of the forest industry, it would take 50 years. If a long-term growth rate of production of the biotechnology sector is sustained at the same level as in the forecast period 2001–2006, it would take 15–30 years to reach the same production level as the electronics or pulp and paper industry has today.

The healthcare sector offers a domestic market potential for biotechnological applications

The healthcare sector's domestic service production was at relatively high level compared even with highly export-oriented industries unto the economic slump during the beginning of 1990s (Figure 4). Since the depression, the growth rates of healthcare service production has been moderate. However, the massive healthcare sector has reached a major crossroads owing to the ageing of the population and advances made in medical science. On the one hand, the ageing population and the medical ability to diagnose and treat more illnesses than before increase the cost pressures on healthcare. On the other hand, biotechnology applications are expected to spawn cost savings over the long term by, for example, making time-consuming diagnostic methods more efficient and facilitating targeted therapy. Below are some policy implications on how the Finnish biotechnology industry could offer solutions to control for a cost crisis in healthcare while at the same time spurring development of an internationally competitive industrial cluster.

The Finnish biotechnology industry could offer solutions to control cost crisis in healthcare

Healthcare cost crisis and growth potential of biotechnology

As seen above, biotechnology is often linked with drug development and various types of healthcare applications such as diagnostics and biomaterials (Figure 1). Almost 60 per cent of the small and medium-sized biotechnology companies indicate that they operate in the pharmaceutical industry or have ties with clients in the pharmaceutical industry. Fields linked indirectly with healthcare include functional foodstuffs, enzymes and assorted research services. However, the Finnish pharmaceutical industry and other healthcare-related industries are nevertheless relatively small on a global scale.

Inaccurate diagnoses or a lack of appropriate treatment lead to a wasteful use of personnel resources and medication. In other words, if the illness is not known or it cannot be treated, the patient has to undergo time-consuming procedures and the treatment may have to be changed numerous times. The patient may have to be institutionalised owing to inefficient treatment. If more efficient ways can be found to make diagnoses and treat patients that would otherwise need long-term care, relatively expensive methods can generate cost savings by shortening the duration of treatment times (see the Appendix; Hermans and Kulvik[18]).

There is an increase in cost pressures on healthcare because of the ageing of the population and the medical ability to diagnose and treat more illnesses than before. However, if the biotechnology industry can develop new biotechnological applications, which make time-consuming diagnostic methods significantly more efficient and which facilitate targeted therapies, some cost savings can be spawned by reducing the need for long-term patient care owing to inaccurate treatments. If in such cases, the long-term savings are higher than the increase in the direct costs of acute healthcare, and the adoption of new technologies can even be expected to induce savings in the total healthcare expenditures. This, however, preconceives an integration of healthcare policies over the acute and long-term care planning.

In Finland there are several types of diseases that are significant from a public healthcare perspective, the treatment of which have considerable macroeconomic effects. The macroeconomic effects can entail costs other than those stemming directly from healthcare. For example, worker absenteeism and premature

pensions affect the productivity of various industries.

Finns' major illnesses have steered the allocation of domestic research resources producing centres of expertise

Illnesses significant from a public healthcare perspective have steered the allocation of domestic research resources, which has spawned internationally significant areas of expertise in medical science and related fields. The research knowledge and demand for its commercial applications arising from these kinds of public healthcare needs enable the domestic market to be used as a commercial test market. Finnish end-users of healthcare products represent the top experts in their fields; this test market promotes the product development of biotechnology companies and development of service concepts as well as preparing companies' products and services to compete on international markets.

CONCLUSIONS

Policy implications

Finland's biotechnology industry has comparative advantages in specific niches with substantial market potential

A small open economy cannot do everything itself. From the standpoint of innovation intensity, the safeguarding of sufficient critical mass is of profound importance if the emergence of a biotechnology industry is deemed worthy in Finland. In order to foster the success of biopharmaceutical companies, a business concept ranging 'from services to development of own drugs' must be developed, which will also spawn profitable business activities in the pharmaceutical sector. The protection of intellectual property rights and utilization of business expertise right from the onset of the research projects will help biotechnology companies receive financing and launch successful business activities.

Sufficient innovation inventiveness and critical mass must be defined and obtained

Industrial history shows us that if a region or a country has no previous industrial traditions in a certain sector, successful businesses and new growth emerge slowly or only seldom. Finland has pinned high hopes on biotechnology as a source of new research-intensive growth. Almost all industrialised countries have the same goal, and many of them already have long traditions in this sector, unlike the short history in Finland. The biotechnology sector's volume of production measured by value added is about €500m. The growth of the biotechnology companies can be facilitated by directing resources to niches where Finland has comparative advantages and where the commercial applications have substantial market potential in the future.

The following discusses five implications broadly derived from the viewpoints above.

Market structure and regional concentration

The significant relation between innovation intensity and location of economic activities derived by Hermans[2] raises some issues on policy implications. The emerging knowledge-based industries (such as the biotechnology industry), which can guide the formation of new spatial agglomerations in the future. According to List's traditional infant industry argument (see, eg, Krueger and Tuncer[19] for seminal empirics and Symposium on infant industries[20] for more recent discussion), the temporary governmental protection of a new emerging industry displaying considerable market potential can be justified especially within small peripheral economies, which lack economies of scale in their production activities.

Implication 1: Sufficient innovation intensiveness and critical mass must be obtained and defined in the individual biotechnology competence segments in the future if Finland wants to have an economy based on knowledge, instead of, for example, wage cost advantages. The extent to which the infant industry argument should be applied to the biotechnology industry need to be investigated in order to secure the viability of the geographical periphery, such as Finland.

The price–cost structure in the pharmaceutical industry

The price–cost structure[3] in a small economy with price controls, seems to be the same as in a large economy without price controls. The Finnish regulatory environment concerning drug development and pharmaceutical markets has recently changed: international trade barriers have decreased and there is also a harmonisation process in patent regulation within EU. This indicates that the Finnish pharmaceutical industry will probably not be able to earn as high margins as previously. In order to bolster up the profitability of the pharmaceutical industry, companies outsource their research and development because of the considerable risk associated with these activities.

A clear synergy potential between large Finnish pharmaceutical companies and small biotechnologically advanced companies

Implication 2: In the near future it will be possible to operate profitably as a small entrepreneur in certain niches in the pharmaceutical sector. Some large Finnish pharmaceutical companies could strengthen their position in global markets by collaborating with small and technologically advanced Finnish biotechnology companies. The kind of collaboration could offer synergy in the combination of most modern technology of small biotechnology companies and resources and logistics of a large pharmaceutical company.

For a value creation perspective, positive cash flows are crucial in the start-up phase

The investigation of financial sources and business strategy of biopharmaceutical companies

Hermans[4,5] confirmed that the main sources of financing for young companies are the persons working at the company, private venture capitalists and the public sector. The growth expectations of young companies point far into the future. The older biopharmaceutical companies owned by other firms have already been able to generate revenues, which is indicative of the pharmaceutical industry's new strategy of outsourcing R&D activities.

A balanced management of a company's intellectual captial requires introduction of business expertise at an early stage

Implication 3: The equity financing of biopharmaceutical companies in the start-up phase is based on the premise that the investors presume they can exit at a later stage. In the current situation in the international financial markets the most common way to exit is via an acquisition or other type of restructuring – in the future also via an initial public offering. The company is an attractive target for acquisition and its value will simultaneously grow when the company has begun to produce considerable amounts of revenues or its product development has proceeded far enough. This calls for dynamic corporate strategies, in which positive cash flows can be generated even at the start-up phase of the company in order to finance the later development phases of the company's products.

The analysis of intangible assets and growth potential of Finnish small and medium-sized biotechnology companies

Hermans and Kauranen[6] conclude that when a company's intellectual capital (human capital, structural capital and relational capital) are balanced and soundly managed, the company's present value is relatively high (see also Hermans and Kulvik[21]). Then potential investors or buyers of the company are able to make a strategically justified estimate of the company's future earnings expectations and the present value. Financing paves the way for the company to turn its innovations into commercial products.

Implication 4: The management of biotechnology companies' intangible assets and competencies is an important measure of future earnings expectations and therefore the company's present value. Thus the integration of business expertise from the start as a part of the technological development occurring in the network of biopharmaceutical companies helps determine whether the company's business strategy is based on development of the market potential of products, not just technological competencies. In practice, the biotechnology industry could utilise the business skills of the managers of other

sectors, such as information and communication technology cluster, in which Finland holds a fairly experienced management (see also Tahvanainen[22]).

The growth forecast for the biotechnology industry

Hermans and Kulvik[7] present the SMEs in the biotechnology industry as a sector of its own. Growth impacts of the biotechnology industry extend to many sectors, foremost the chemical industry, which includes also the pharmaceutical sector.

The Finnish biotechnology industry can create a sustainable comparative advantage

Implication 5: The biotechnology industry as a distinct sector will not become one of the main pillars of the Finnish economy for at least a decade, even if the growth is swift. It is likely that the Finnish economy's new engine of growth will emerge from a combination of already existing expertise in old sectors with the technological leaps in new sectors. In this case, biotechnology may play a significant role. To fulfil the anticipations, there is a need for the creation of a critical mass of factors of production and comparative advantage by building collaboration and financing networks between the biotechnology industry and traditional industries, such as the forestry, electronics and pharmaceutical industries.

Topics for further research

Further research is needed to evaluate which potential niches the biotechnology sector should seek to fill when developing products with commercial potential. When seeking to identify these niches, it is important to keep in mind that the competence base must be sufficiently large to generate the critical mass necessary for spawning products and services with sufficiently large market potential. We can look at the prerequisites for turning research into commercial products from the standpoint of the competence base underlying this critical mass: knowledge-intensive entrepreneurship, financing possibilities and international market potential.

- By distinguishing the main incentives and barriers regarding entrepreneurship in a research segment with a deep competence base. In addition, by investigating the distribution of key research areas and biotechnology companies that have already emerged, we can seek to find niches that not only have a considerable competence base but also a 'commercialisation gap'.

- By analysing the preferences of financiers investing in biotechnology companies, which are then compared with the distribution of the competence base of biotechnology research. This reveals to what degree the financiers have been able to utilise the Finnish competence base.

- By analysing and comparing the international market potential to Finland's competence base. This topic offers analysis on what kind of market potential can be related to the Finnish competence base.

This type of further research would be beneficial for planners of general technology policies and stakeholders in various sub-sectors of the biotechnology industry. Technology policy experts can benefit from the research results when gauging use of alternative types of support in light of the principle of comparative advantage based on international trade analysis. In Finland substantial amounts of state aid are directed to the biotechnology sector. The private and public investment activity is rather modest by international standards. Resources should thus be allocated prudently.

Biotechnology research can be applied in many diverse areas. There is a danger that when making financing decisions the authorities are unable to 'see the forest for the trees'. Therefore, start-ups that base their activities on isolated top-notch research fields may end up without financing. A reason can be the lack of a viable business plan even if the segment has considerable market potential.

Further research should offer such new information about the biotechnology sector that would assist public and private financiers in better understanding the biotechnology sector and its companies. A proper understanding of which domestic top-notch research fields might offer applications with the highest market potential is necessary for making sound decisions when steering scarce resources.

APPENDIX
Case study: Use of biotechnology in treating strokes – more efficient treatment leads to savings[23–25]

Stroke is the most common type of blood-circulation-disturbance in the brain. The acute phase requires several days of intensive surveillance, which has led to an increse in treatment costs. In 1999 about 6 per cent of total healthcare expenses were related to treatment of strokes. The treatment of patients suffering from brain circulation disorders takes an average of 2.5 years, which in Helsinki costs about €100,000.[26] Fogelhom *et al*.[27] estimate that the ageing of the population means that the need for acute treatment will double by the year 2030.

The nuerological policlinic of the Helsinki University Central Hospital (HUCH) has started to treat stroke patients with so-called trombolytic therapy, where a doctor tries to remove a blood clot by dissolving it. Alteplase, a drug produced in hamster ovarian cells by the aid of recombinant DNA technique, is the most widely used thrombolytic agent. Despite the favourable results obtained by the thrombolysis, it has two drawbacks. First, the medication is relatively expensive- one dose costs over €1,000. Secondly, the trombolysis must be started quickly- three or four hours following the onset of symptoms.

In 2002 about 8 per cent of the stroke patients coming to the HUCH neurological clinic received the solvent treatment with good results. About 60 per cent of the patients receiving thromobolysis recovered. The total cost savings with respect to the recovered patients were about €84,000 per patient, which represents over 80 percent of the non-recovering patients' total costs.[28]

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Appendix 2. Price-cost Margin in the Pharmaceutical Industry

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Price-cost margin in the pharmaceutical industry

Empirical evidence from Finland

International comparisons of pharmaceutical prices are used for regulatory purposes in several countries. Information is gathered on relative price levels of pharmaceuticals in different countries. This information together with information on the costs of producing the pharmaceutical R&D costs and cost-effectiveness can then be utilized in the decision-making concerning the price regulation of pharmaceuticals.

Direct price comparison studies have been subject to criticism. Danzon and Chao [7] demonstrate that international comparisons might lead to biased results if based on unrepresentative samples and unweighted indices of pharmaceuticals. Furthermore, such price comparisons may also be insufficient for the purpose since price comparisons do not provide information on factors behind the observed price differences. Price differences may be the result of different degrees of competition, differing regulatory practices, differences in the costs of production, and income differences across countries. Direct measurement of price-cost margins would provide some further information on factors influencing price differences in pharmaceutical markets. To our knowledge, there is limited information on price-cost margins of the pharmaceutical industry particularly in those countries with price regulation. This study takes a step in that direction.

The aim of this contribution is to estimate the price-cost margin in the Finnish pharmaceutical industry. This study concentrates on a single country for two reasons. First, international data, which would allow us to make more general conclusions on price-cost margins, were not available. However, we are able to compare our results with those in the United States market [14]. Second, we wanted to test the functionality of the applied method in measuring the performance of pharmaceutical markets in one country to see whether this method could be utilized in international comparisons.

The method developed by Hall [11] and later applied by Domowitz et al. [8] is utilized in this study. This method does not require strong assumptions on consumer preferences and is suitable for analysis of aggregate data sets with small number of observations. Estimation of the price-cost margin is based on Solow's residual, as the method for the measurement of technical progress originally invented by Solow [15] is sometimes called. Hall [11] demonstrated that the residual is independent of the growth of output-capital ratio in a competitive industry, but that under imperfect competition a positive correlation between the two variables appears. The total factor productivity growth is therefore procyclical under imperfect competition, and estimation of the price-cost margin can be based on this observation. According to our results, the estimated price-cost margin in the Finnish pharmaceutical industry falls into the range 0.59–0.67 depending on the instrument variable used in estimation.

This contribution is organized as follows. We first describe the theoretical background, empirical methods, and data used in this study. We then present the results of the estimation. The following section discusses possible interpretations of the results when assessed from the perspective of the R&D process and price regulation of pharmaceuticals. The results are also compared with those of other studies.

Methods and data

Measurement of the price-cost margin has been considered problematic due to the lack of appropriate marginal cost data. Scherer and Ross [14] (see also [13]) approximate price-cost margins using accounting data. Such approximations may be biased measures of price-cost margins since they typically contain cost measures, which do not approximate marginal costs [4,14]. Bresnahan [2,3] and Hall [11] have developed methods for estimating market power directly from sales and industry data. Due to the nature of the data we utilize Hall's method, which concentrates on comparing total factor productivity growth under perfect and imperfect competition.

Theoretical set-up

Solow's residual in competitive markets

Let us first derive Solow's residual in a perfectly competitive industry. Consider a linearly homogeneous production function with neutral technical progress:

$$Q(t) = A(t)f(L(t), K(t)) \qquad (1)$$

where A is a measure of the technical progress, Q measures output, and L and K measure labor and capital inputs. It is assumed that all the variables are measured at a certain point in time, which is signified by making all the variables depend on time, t. To simplify the notation, however, the time variable is dropped from the following derivation. Totally differentiating the production function (Eq. 1) with respect to time and then multiplying the resulting equation by the inverse of output yields:

$$\frac{\dot{Q}}{Q} = \frac{\dot{A}}{A} + A\frac{f_l(L,K)}{Q}\dot{L} + A\frac{f_k(L,K)}{Q}\dot{K} \qquad (2)$$

Here f_l and f_k denote the partial derivatives of the production function with respect to labor and the capital, respectively, and all the dotted variables denote the time derivatives. Let us rewrite Eq. 2 as:

$$\frac{\dot{Q}}{Q} = \frac{\dot{A}}{A} + A\frac{f_l(L,K)L}{Q}\frac{\dot{L}}{L} + A\frac{f_k(L,K)K}{Q}\frac{\dot{K}}{K} \qquad (3)$$

In a perfectly competitive industry, labor and capital are compensated according to their marginal productivity. Suppose that labor and capital use are $\tilde{K}$ and $\tilde{L}$ and let c, p, w and i denote marginal cost, market price, nominal wage, and rental price of capital, respectively. Perfect competition implies that price is equal to marginal cost, and labor obtains an equilibrium real wage $w/p = Af_l(\tilde{L}, \tilde{K})$ and capital obtains a real rental price $i/p = Af_k(\tilde{L}, \tilde{K})$ in equilibrium. Equation 3 can then be rewritten as:

$$\frac{\dot{Q}}{Q} = \frac{\dot{A}}{A} + \frac{wL}{pQ}\frac{\dot{L}}{L} + \frac{iK}{pQ}\frac{\dot{K}}{K} \qquad (4)$$

$$= \frac{\dot{A}}{A} + \frac{wL}{cQ}\frac{\dot{L}}{L} + \frac{iK}{cQ}\frac{\dot{K}}{K}, \qquad (5)$$

where the last equality follows from perfect competition. In Eq. 4, $\frac{wL}{pQ}$ and $\frac{iK}{pQ}$ are the ratios of labor and capital compensation to the value of production, referred to below as the shares of labor and capital. Let us denote the shares of labor and capital by s_l and s_k, respectively, and competitive labor and capital shares as $\tilde{s}_l$ and $\tilde{s}_k$. Competitive shares are the shares of labor and capital under perfectly competitive product market when output is valued at marginal cost. Competitive shares of labor and capital are defined as $\tilde{s}_l = \frac{wL}{cQ}$ and $\tilde{s}_k = \frac{iK}{cQ}$. The assumption that the production process is linearly homogeneous implies that under perfect competition, with zero profits, the shares of labor and capital add up to 1. Under this assumption Eq. 4 implies that:

$$\frac{\dot{Q}}{Q} - \frac{\dot{K}}{K} - \tilde{s}_l\left(\frac{\dot{L}}{L} - \frac{\dot{K}}{K}\right) = \frac{\dot{A}}{A} \qquad (6)$$

The left side of Eq. 6 measures the difference between the growth rate of the output-capital ratio and the growth rate of the labor-capital ratio weighted by labor's share. Since Solow [15], this measure has been used to quantify the growth rate of total factor productivity, or technical change, and has also been called Solow's residual. The residual measures the change in output unexplained by changes in labor and/or capital.

Solow's residual under imperfect competition

Hall [11] analyzed Solow's residual by relaxing the assumption on perfect competition in the product market. Let us assume that the market is imperfectly competitive, and define the Lerner index as I=(p-c)/p. Under imperfect competition price exceeds marginal cost, and the Lerner index obtains a strictly positive value. Now the competitive share of labor can be rewritten in a generalized form as:

$$\tilde{s}_l = \frac{p}{c}\frac{wL}{pQ} = (1-I)^{-1}s_l \qquad (7)$$

Using the generalized form for competitive share of labor, Eq. 6 can be rewritten as follows:

$$\frac{\dot{A}}{A} = \frac{\dot{Q}}{Q} - \frac{\dot{K}}{K} - (1-I)^{-1}s_l\left(\frac{\dot{L}}{L} - \frac{\dot{K}}{K}\right) \qquad (8)$$

Multiplying both sides of Eq. 8 by (1-I) one obtains:

$$\frac{\dot{A}}{A}(1-I) = \left(\frac{\dot{Q}}{Q} - \frac{\dot{K}}{K}\right)(1-I) - s_l\left(\frac{\dot{L}}{L} - \frac{\dot{K}}{K}\right) \qquad (9)$$

which implies:

$$\left(\frac{\dot{Q}}{Q} - \frac{\dot{K}}{K}\right) - s_l\left(\frac{\dot{L}}{L} - \frac{\dot{K}}{K}\right) = \frac{\dot{A}}{A}(1-I) + I\left(\frac{\dot{Q}}{Q} - \frac{\dot{K}}{K}\right). \qquad (10)$$

The left side of Eq. 10 is generalized Solow's original residual, which under imperfect competition is no longer independent of the growth of the output-capital ratio, but the technical progress is now procyclical. This is because under imperfect competition price exceeds marginal cost and I is greater than 0. Properly specifying an econometric model on this result allows one to make inferences on the Lerner index using data on the output, the labor and the capital.

This model specification differs from the model used originally by Hall [11] but is consistent with the specification used by Domowitz et al. [8]. Hall's specification allows one to estimate the price-cost ratio of a particular industry, but in the above model specification the Lerner index is the unknown parameter. It can be shown that the two approaches are equivalent, and that there is no loss in using either model specification. If the price-cost margin is estimated then the price-cost ratio can be directly derived and vice versa.

Empirical model

Our empirical model is based on generalized Solow's residual derived in the previous subsection. A following econometric model is specified on the basis of Eq. 10:

$$r_t = \alpha_1 + \alpha_2 q_t + u_t \qquad (11)$$

In the model r_t is Solow's residual in year t (the left side of Eq. 10). The parameter α_1 is a measure for technical progress, adjusted by the Lerner index. The term q_t is the growth of the output-capital ratio in year t and the regression coefficient α_2

Table 1

Descriptive statistics of original data (n=25)

Variable	Minimum	Maximum	Mean	SD
Places of business	8	15	11.76	1.96
Number of workers	1,874.00	3,787.00	3,130.64	565.83
Working hours[a]	3,318.00	6,182.00	5,162.75	815.16
Wages[b]	47,806.00	522,209.01	296,170.28	164,955.10
Value added, 1995 prices[b]	332,638.74	1,415,464.13	952,073.34	305,810.44
Value added, current prices[b]	135,820.00	1,469,393.31	758,821.37	404348.98
Total output, 1995 prices[b]	581,338.98	2,774,158.08	1,921,561.05	636,518.61
Total output, current prices[b]	237,367.00	2,879,853.50	1,541,262.82	818,856.61
Capital stock/working hours	80.28	295.50	213.90	78.49

[a]*Thousands*
[b]*Thousand Finnish marks*

Table 2

Share of labor and growth rates of value added, capital stock, labor hours and total factor productivity in Finnish pharmaceutical industry (%)

Year	Value added	Capital stock	Labor hours	Productivity	Share of labor
1975	–	–	–	–	35.198
1976	82.853	12.088	7.866	71.845	25.584
1977	9.982	19.516	6.650	–5.923	28.060
1978	5.032	21.244	1.886	–10.674	28.608
1979	–14.873	–21.086	9.231	–4.509	35.367
1980	1.377	41.574	10.358	–28.557	37.287
1981	14.780	41.646	2.602	–13.282	34.791
1982	4.039	29.685	–2.266	–14.809	33.916
1983	–8.620	26.434	9.977	–28.292	41.090
1984	14.832	8.512	10.155	5.613	43.069
1985	16.527	8.450	3.073	10.349	42.235
1986	–14.700	–0.235	–1.959	–13.615	49.304
1987	25.664	11.724	–1.807	19.606	41.871
1988	24.921	–5.242	–1.327	28.733	36.537
1989	9.165	5.803	2.995	4.356	35.410
1990	1.476	9.164	7.644	–7.067	40.859
1991	1.463	–1.401	–6.470	4.861	39.406
1992	–8.291	4.356	–2.836	–9.738	40.452
1993	–10.493	–3.588	4.183	–10.057	40.559
1994	0.610	0.756	–1.674	0.889	42.607
1995	13.057	0.751	3.406	11.237	40.254
1996	–1.619	–2.682	–5.781	2.283	39.389
1997	–1.654	–5.944	–6.938	4.668	38.033
1998	1.688	5.825	2.753	–2.859	41.610
1999	15.631	–1.668	–2.437	17.572	35.539
Average	7.619	8.570	2.053	1.360	37.881

measures the Lerner index. A positive value of α_2 signifies that there is market power in the industry. Theoretical considerations suggest that the value of α_2 should be constrained between 0 and 1.

We make the following assumptions concerning the model. It is assumed that the statistical error terms u_t are normally distributed with zero mean and variance σ^2. Furthermore, it is assumed that there is no autocorrelation of any order in error terms.

The above assumptions together with the assumption that the explanatory variable of the model has no correlation with the error term would be sufficient for the OLS estimates of α_1 and α_2 to have all desirable properties. It should be observed, however, that any shock causing a change in the growth rate of the output-capital ratio and less than a proportional change in the growth rate of the labor-capital ratio causes a simultaneous change in the independent variable of the model, the growth rate of total factor productivity. Therefore the dependent and independent variables are determined jointly, which creates a correlation between the error term and the independent variable of the model and renders the OLS estimates of the parameter α_2 inconsistent and biased. We applied 2SLS estimation techniques to correct the problems due to an endogenous dependent variable.

Data

The data set was aggregated from firm-level data and contains all Finnish pharmaceutical firms having more than 20 employees. The firm-size restriction was made to avoid the problem of inconsistent data in the capital stock variable. The capital stock figures for the smallest places of business were assessed to be unreliable over time.

The data set covers the time period from 1975 to 1999 and contains information on nominal and real output, nominal and real value added, working hours, number of workers, wages, and capital stock. The capital stock series was constructed from data on capital stock per labor hours. ◘ **Table 1** below presents the descriptive statistics of the original variables used in this study. Output, value

added, wages, and capital stock variables are measured in Finnish marks.

Volume indices for output and value added were constructed in Statistics Finland and are presented in 1995 prices. Excluding the instrument variables, we received ready-made data in both value and volume terms. As instruments we used total expenditure on pharmaceuticals and gross national disposable income. Data on the first instrument were obtained from the Social Insurance Institution of Finland, while all the other data came from Statistics Finland.

Our data set is unique in the sense that it was constructed from the micro-data sources for our purposes. Although the data set is constructed from micro-data in Statistics Finland, we have no access to firm level information. This places restrictions on empirical methods we can use. The privacy protection of single firms usually leads to the problem of data availability in a small country such as Finland. This causes difficulties in data releases, especially in industries with few large companies. In our data set, which is based on the micro-level places of business, this information problem did not arise. The data do not include the smallest places of business for each year of the observation period. Therefore the time series are consistent during the entire period.

Variable construction

In order to construct theoretically based variables we first computed the growth rates of production (value added), capital stock and labor hours. We then took the difference between the growth rates of output and capital stock, labor hours and capital stock, and the residual difference between these two. In the residual the growth rate of the labor-capital ratio was weighted by labor's share.

Instrument variables for the analysis were chosen so that the variables would affect the growth rate of the output-capital ratio through their effects on the demand for pharmaceuticals, but presumably they have no effect on technical progress in the pharmaceutical industry. The instrument used for the growth rate of the output-capital ratio was the prediction from the linear model in which the growth rate of the output-capital ratio was regressed on the growth rate of pharmaceutical expenditures. A priori one could argue that the growth rate of pharmaceutical expenditures should be correlated with the output growth in the pharmaceutical industry, but there is no reason to expect that the variable would be correlated with the error term of the econometric model [11].

Pharmaceutical expenditures were not deflated to 1995 prices, on the grounds that the prices of pharmaceuticals are expected to affect the quantity of pharmaceuticals produced in the pharmaceutical industry. The correlation of the instrument used and the growth rate of the output-capital ratio was 0.62, while the correlation of the growth rate of pharmaceutical expenditures in 1995 prices, and the growth rate of the output-capital ratio was 0.55. Hence pharmaceutical expenditures in current prices has a higher correlation with the explanatory variable of the model [11] than pharmaceutical expenditures in 1995 prices, which supports the theoretical idea that we used to select the instrument.

We also used national disposable income as another instrument for two reasons. First, we wanted to test the sensitivity of the results with respect to the chosen instrument. Second, only some part of the pharmaceuticals consumed in Finland are produced domestically which is why pharmaceutical expenditures may not be correlated perfectly with domestic production. As in other industrial branches, a part of the domestic production of pharmaceuticals is exported. National disposable income was selected as another instrument, since exports are an important determinant of production and therefore national income. Obviously, this choice relies on the assumption that pharmaceutical exports vary in parallel with aggregate exports.

In order to increase the correlation between the independent variable of the model [11] and the instrument we subtracted the growth rate of capital stock from the growth rates of the two instrument variables.

Results

Table 2 displays the rate of growth of value-added, labor, capital and productivity,

Abstract

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Price-cost margin in the pharmaceutical industry. Empirical evidence from Finland

Abstract
This contribution estimates the price-cost margin in the Finnish pharmaceutical industry. The estimation is based on the method developed by Hall who shows that under constant returns to scale total factor productivity growth depends on the growth of output-capital ratio if the market is imperfectly competitive. Measurement of the price-cost margin is based on this theoretical result. We utilize data on the Finnish pharmaceutical industry. The data cover the years 1975–1999 and include information on output, labor hours, and capital stock. The results show that the estimated price-cost margin is in the range 0.59–0.67, which is close to the estimates obtained in the United States market.

Keywords
Pharmaceuticals · Pricing · Competition

and labor's share in the Finnish pharmaceutical industry in the period 1975–1999. The average rate of growth of value-added was approximately 7.6% in this period while the average rates of growth of capital and labor were 8.6% and 2.0%, respectively. This implies that labor productivity has been increasing, while the productivity of capital has been declining in the Finnish pharmaceutical industry during 1976–1999. The rate of growth of the total factor productivity, measured as Solow's residual, has been on average 1.4% over the same time period. The average labor's share has been approximately 0.38 and slightly increasing over time.

The data suggest that total factor productivity growth in the Finnish pharmaceutical industry is strongly procyclical. This is evidenced by the positive correlation between the rate of growth of total factor productivity and that of the output-capital ratio. The estimated correlation coefficient is 0.978, which differs significantly from zero ($P<0.01$). **Table 3** displays the OLS estimation results of the linear model [11], in which Solow's residual is regressed on the growth rate of the output-capital ratio. As expected on the basis of the above correlation estimate, the explanatory power of the model is high, and the growth rate of output-capital ratio significantly explains the variation in Solow's residual.

As argued above, the OLS estimate of the parameter α_2 is inconsistent and biased. The following table (**Table 4**) presents the results based on 2SLS estimation, which aims at correcting the problems of the OLS estimates. The instrument used in model 1 is the growth rate of pharmaceutical expenditures, and in model 2 the growth rate of national disposable income. **Table 4** displays the results of 2SLS estimation for both instruments.

According to the results of model 1, the estimated Lerner index is positive and differs significantly from 0. The estimated value of the price-cost margin is 0.67, which implies an approximate price-cost ratio of 3.01. Both variables in the model jointly explain the variation in Solow's residual in a significant way, as the value of the F test shows. The high value on the F test is consistent with the relatively high value of the coefficient of determination, R^2.

In model 2 the estimated price-cost margin is 0.59, which is below the estimate obtained in the model 1. The correlation of the second instrument with the rate of growth of output-capital ratio is lower than that of the first instrument. This leads to a higher standard error of the parameter estimate of α_2 in model 2 than in model 1. In model 2 the estimated price-cost margin implies a price-cost ratio of 2.4.

Discussion

The above analysis provides estimates for the Lerner index in the Finnish pharmaceutical industry. As the results indicate, the estimated price-cost margin falls in the range 0.59–0.67 depending on the instrument used. Carlton and Perloff [5] list results from studies estimating price-cost margins in different industries. The highest price-cost margins appear in regulated banking (=0.88) and coconut oil industry (=0.89). Our estimates on price-cost margin are below these two estimates. Scherer and Ross [14] utilize accounting data and find that the United States pharmaceutical industry has the sixth highest price-cost margin when industries are ranked according to the estimated price-cost margins. The authors estimate the price-cost margin to be 0.614. On the basis of informal discussions, Berndt et al. [1] assess that price-cost margin for H_2 antagonists would fall into the range 0.75–0.9.

Our estimates are close to the results obtained by Scherer and Ross [14] in the United States. This is slightly surprising when the market environment of the pharmaceutical industry is taken into consideration. There is no price regulation in the United States, whereas prices of pharmaceutical products are subject to price regulation in Finland. Previous studies (see [7]) have shown that the prices of pharmaceuticals are higher in the United States than in Europe, and the main underlying reason is believed to be price regulation. What is interesting is that, according to our results, there seems to be no significant difference in the price-cost margin between unregulated and regulated pharmaceutical markets. One should stress, however, that more comprehensive data sets and comparable methods are needed in order to draw more general conclusions on the differences between price-cost margins in regulated and unregulated pharmaceutical markets.

In Finland the regulatory system was changed in 1994. Before that time firms faced strict price regulation, and whenever a product obtained a market authorization, a regulated price was given to the pharmaceutical. After 1994 price regulation of pharmaceuticals was tied to the reimbursement system in a way that whenever a pharmaceutical is accepted to the list of reimbursed drugs, the price regulation is put into a force. Wholesale price of the drug is required to be reasonable in comparison to prices in other countries in Europe. Regulation defines a price cap level and firms can select prices below the regulated price [12].

When interpreting our results, it is important to observe that not all pharmaceuticals are reimbursable and price regulated in Finland. Our analysis is based on aggregate data and all pharmaceuticals are included. In the United States, aggregate markets can be divided into those pharmaceuticals under patent protection and those facing generic competition. Danzon and Chao [7] show that price differences between United States and European markets can be low when prices of generic products are included in price comparisons. Similar price-cost margins in Finland and the United States may be due to such dichotomous market structures in both countries.

Another interesting policy question is the impact of regulatory changes on price-cost margin. To test the effect of the regulatory change in 1994 we estimated two separate models for periods 1975–1993 and 1994–1999. The price-cost margin increased in the latter model but the results are unreliable due to low number of observations and low statistical significance of the estimates. A similar result is obtained from the model with dummy variable interacting with independent and instrument variables of the model.

Compared with efficient pricing practices, namely marginal cost pricing, it seems that the estimated price-cost margins in pharmaceutical markets are high. Marginal cost pricing may not be a realistic pricing scheme in the pharmaceuti-

cal industry, as has been pointed out by several authors (e.g., [6, 13]). Before launching their products pharmaceutical firms use resources on research and development, which tends to lower the firm's profitability after entering the market. It has been shown that if R&D costs are taken into consideration, the annual profitability of firms in the pharmaceutical industry is not much higher than in other industries [13]. In this study we have not considered explicitly R&D costs of the Finnish pharmaceutical industry. Some part of the estimated margin probably contains R&D costs, and it is expected that the estimated price-cost margin would be lower than the margins presented above if entire R&D costs could be included in the data. To measure the impact of R&D expenditure on price-cost margin a further study with wider data sets is needed.

Before concluding this contribution we would like to raise two methodological questions related to the method and data used in this study. First, the methodology used to estimate the price-cost ratio is built on the assumption that production technology is characterized by constant returns to scale. Hall [11] demonstrated that the correlation between Solow's residual and the growth of the output-capital ratio predicted by an instrument may also appear if there are increasing returns to scale in production technology. Time-series data without cross-sections utilized in this study do not allow us to directly test whether the assumption on constant returns to scale holds true in our data set. This is because there may be technical progress, shifting the production function of pharmaceuticals inwards or outwards, and any conclusions concerning the economies of scale might be erroneous since technological progress cannot be controlled at the same time. Firm- or country-level panel data would be sufficient for tests concerning the economies of scale. If increasing returns to scale are present in the Finnish pharmaceutical industry, obtained estimates for market power are too high because some part of the positive estimate is due to increasing returns to scale in production [11].

The second question concerning the data arises from the properties of the 2SLS estimates, which are biased but consistent [9]. Our data set is relatively small, and hence there may be some bias in our estimates. Longer time series data or panel data sets would be preferable so that one could resort to large sample properties of the estimates.

Table 3

OLS results of the model 11; all estimates use LIMDEP [10] (n=24)

Parameter	Estimate	Standard error	P
α_1	2.199	0.893	0.022
α_2	0.882	0.040	<0.01
R^2	0.956	–	–
F test[a]	480.46	–	<0.01
DW[b]	1.814	–	–

[a] *F test for model significance*
[b] *Durbin-Watson statistic for autocorrelation*

Table 4

2SLS results of the model 11 (n=24)

Parameter	Model 1			Model 2		
	Estimate	Standard error	P	Estimate	Standard error	P
α_1	1.995	1.350	0.123[a]	1.919	1.655	0.226[a]
α_2	0.668	0.098	<0.01[a]	0.588	0.155	<0.01[a]
R^2	0.9	–		0.85	–	
F test[b]	198.27	–	<0.01	125.01	–	<0.01
DW[c]	1.407	–	–	1.383	–	–

[a] *Probabilities computed from standard normal distribution, two-way testing*
[b] *F test for model significance*
[c] *Durbin-Watson statistic for autocorrelation*

Conclusion

This article estimated the price cost margin in the pharmaceutical industry. We used data on the Finnish pharmaceutical firms and applied the methodology introduced by Hall [11]. This methodology essentially rests on measuring the correlation between growth rates of total factor productivity and the output-capital ratio. We utilized the 2SLS estimation methodology in the empirical section of this study. According to the results, the estimated range for the price-cost margin is 0.59–0.67, which is close to estimates obtained in the United States pharmaceutical industry [14].

The data set used is unique in the sense that it is aggregated from firm-level observations and contains all Finnish pharmaceutical firms having more than 20 employees on their payroll. The time series cover the years 1975–1999. However, the nature of the data also puts some limitations to our study. First, since we had no access to panel data, we were not able to test whether the assumption concerning constant economies of scale holds true in our data. Second, the obtained data set is quite small, which also puts some limitations on the results obtained.

Future work could extend in three directions. First, with the help of international data sets, the estimates of price-cost margins could be estimated in settings in which several countries are present simultaneously. This could provide interesting information on price-cost margins in different countries with different market environments. Such information could be used in the price regulation of pharmaceuticals. Second, due to the strongly innovative nature of pharmaceutical industry it would be beneficial to add R&D expenses in the analysis of price-cost margins in further research. Third, it is important to apply different methods to measure price-cost margins in order to assess the possible impacts of different assumptions behind the models.

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Appendix 3. Growth Inhibitors of Entrepreneurial Academic Spin-Offs

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GROWTH INHIBITORS OF ENTREPRENEURIAL ACADEMIC SPIN-OFFS: THE CASE OF FINNISH BIOTECHNOLOGY

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This study compares Finnish biotechnology SMEs founded by the academic originators of the underlying basic research projects with biotechnology companies of other origins. The comparison facilitates the identification of factors affecting the prosperity of these "academic spin-offs" as a business. Results indicate several inhibitors of growth: Academic spin-offs lack market-orientation and commercial skills, the traditional perception of the academia's detached role within society aggravates the recruitment of skilled labour, and Finland's equity markets are underdeveloped with new seed capital being next to unavailable, as private and foreign venture capitalists invest primarily in companies being already very close to the markets.

Keywords: Academic entrepreneurship; biotechnology; small and medium sized enterprises.

1. Introduction

This paper portrays characteristics of Finnish biotechnology SMEs[a] having their origin in academic research conducted in universities or other comparable research institutions. In order to emphasize their entrepreneurial aspects and background, academic spin-offs are defined to be firms founded or at least co-founded by the originator of the academic research a particular firm is commercializing. The focus on these entrepreneurial academic spin-offs is factually justified, as the majority of biotechnology start-ups in Finland exhibit such a background. The aim is to explore whether and how these firms differ from biotechnology firms spun off by

[a]SMEs in this paper are defined according to official definitions of the EU including firms that match the following criteria: (i) Number of employees < 250 AND at least one of the following two: (ii) annual turnover < 40 mill. EUR, (iii) balance sheet total < 27 mill. EUR.

large corporations and other firms that do not build on academic research.[b] To this end, I set the null-hypothesis stating that there is no difference between the two types of firms.

The portrayal contributes to existing literature by providing a detailed first-time look at Finnish academic biotechnology spin-offs. It facilitates the positioning of these firms within the sector as a whole and, even more importantly, enables the identification of strengths and weaknesses of academic biotechnology spin-offs as well as factors that either promote or inhibit their prosperity from an entrepreneurial perspective. Furthermore, findings have implications on future studies aiming at generating (a) knowledge on entrepreneurship that is rooted in academic research, on one hand, and (b) advise for policy making concerning the promotion of industrial biotechnology on the other.

1.1. *Background*

The motivation for studying academic entrepreneurship in a sector that is still regarded to be in its early days of development and of small economic significance at the present, at least from the Finnish perspective, can be traced back to a framework that is in the core of discussions about Finland's competitiveness in the global economy.

According to the principle of comparative advantage, Finland has to focus on generating technological innovations in order to protect its competitiveness, as competition based on mass production and economies of scale are ruled out due to small domestic markets and a high cost level. In the 1990s, the ICT sector bore the function of being the locomotive of innovation and exports growth. As the sector matures and markets saturate due to harsh global competition, Finland has to map and develop new sectors that (a) form a strong platform for technological innovation activities and (b) are of significance on the global scale. Biotechnology is one candidate satisfying both criteria. Understanding the nature of the biotechnology business and its requirements posed to the operational, political and social environments become crucial, if one aims at an efficient and effective policy for the support of the sector. This in turn necessitates profound research, as the sector seems to differ in many ways from more traditional ones.[c]

At the heart of sector growth are start-ups and, in more general terms, entrepreneurship. Growth can certainly be achieved through expansion of existing organizations, but the critical mass forming a self-nurturing network that generates sustainable growth through complementary diversity can only be provided by an expansion of the company base, increasing the sector not only in size but also

[b]Large biotech corporations are excluded from the analysis due to inconsistencies in the data and because one could assume that larger and more mature companies resemble those in other sectors in terms of firm characteristics relatively more than small and medium sized companies due to the more consolidated state of business. Thus, the inclusion of large sized firms might have diluted findings stemming from characteristics distinctive for biotechnology businesses. The question whether this assumption holds true stands open for further research and is not answered to in this paper.

[c]For a comparison of the Finnish biotechnology and ICT sectors refer to Palmberg and Luukkonen [2004].

in scope. Thus, critical attention should be paid to the analysis of start-ups. This paper takes a first step in that direction by shedding light on the characteristics of entrepreneurial academic biotechnology spin-offs.

1.2. *Prior literature*

This study positions itself amongst a fairly young and lean but steadily growing literature on the Finnish biotechnology sector. The first comprehensive disquisitions of the Finnish biotech sector in general are provided by Halme [1994], Halme [1996], Ahola and Kuisma [1998] as well as Tulkki, Järvensivu and Lyytinen [2001]. All three studies are descriptive of nature and incorporate a firm level description of the state of the Finnish biotechnology sector at given times. Hermans and Luukkonen [2002] present quantitative results on the evolution of the sector in terms of the number of established firms, their location and difficulties at the start-up phase, funding, customers and markets, R&D-intensity and collaboration, personnel and skills, sources of funding and intellectual property rights (IPRs).

Hermans and Tahvanainen [2002] is a descriptive study on the capital and ownership structure of Finnish biotech SMEs, whereas Tahvanainen [2003] examines this structure more in-depth in the light of central theoretical frameworks. Hermans [2003] focuses on the capital structure and other characteristics of business operations of biopharmaceuticals in Finland, while Hermans and Kauranen [2003] relate growth expectations of Finnish biotech companies to intellectual capital residing in them.

The literature referred to so far serve the purpose of indicating that there is close to none existing literature focusing explicitly on entrepreneurial academic biotechnology spin-offs in Finland. More relevant to the matter of this study is a sub-branch of the generic entrepreneurship discussion focusing on *academic entrepreneurship*. In the following, I deliberately provide more extensive reviews of these studies as they provide a backdrop for the discussion of results towards the end of the study. As the present study is explorative in nature and examines a variety of isolated aspects related to academic spin-offs, the review does not follow one thematic path but introduces a selection of very heterogeneous studies that all contribute to a deeper understanding of results presented in the present study.

One of the most intensively studied aspects concerns cooperation patterns, networking and cluster formation of firms. Shan, Walker and Kogut [1994] examine the association between inter-firm cooperation and the innovation output of start-ups in the biotechnology industry. Their key finding suggests that commercial ties to other companies are a pre-condition to higher innovation output.

Nilsson [2001] analyzes the role of interaction between researchers, managers, and venture capitalists in the process of recognizing and pursuing emerging opportunities in biotechnology. Whether an actor takes an entrepreneurial role or not in capturing emerging commercial opportunities depends on particular characteristics, like the ability to recognize opportunities in the first place and the relative position "in networks through which financial and human capital can be gathered" [Nilsson (2001), p. 64]. Particular emphasis is laid on interaction, which according to Nilsson is a prerequisite of acquiring and preserving social capital. Social capital, in turn,

is needed to locate complementary human and financial capital that facilitates the pursuit of opportunities in biotechnology. Thus, interaction is regarded to be central to successful commercialization in biotechnology.

Similarly, Powell [1998] sees relationships as a critical pre-condition for knowledge diffusion, learning, and technology development that in turn are vital for keeping up with the competition in the "learning race". Shan [1990] investigates the determinants of entrepreneurial biotechnology firms to establish cooperative agreements. He shows that a late entrant or a follower is more likely to pursue such arrangements than an industry leader. Shan additionally finds that firm size is negatively correlated to the propensity to cooperate. New high-tech firms that try to commercialize a product on foreign markets also seek after cooperation.

Another heavily covered aspect of academic entrepreneurship relates to locational, cultural, and policy issues of different regions and countries. According to Zucker, Darby and Brewer [1998], for example, the geographic location and the point of time where and when firms initially start to utilize biotechnology is positively correlated to where and when star bioscientists are actively producing publications and contributing to the basic science underlying the commercialized technology.

Smith and Fleck [1988] draw a picture on the development phases of business models that biotech firms apply in different stages of their life cycle, especially in order to cope with binding financial constraints in the early phases. They find that firms start with a business logic that requires relatively little capital, e.g. contract research and production as well as different services. These modes generate incoming cash flows much earlier than heavily R&D-intensive modes. As a next step, biotech firms move towards diagnostic products that require substantially more R&D efforts, but reward firms with higher returns on success. The ultimate goal, according to Smith and Fleck [1988], is the development, production and sale of pharmaceuticals, which requires large amounts of capital. Another paper concerning integration and cooperation strategies of commercialization in biotechnology is presented by Pisano [1991].

Deeds [2001] analyzes whether entrepreneurial wealth — as measured by MVA (Market Value Added) — can be related to the R&D-intensity, technological capabilities and the absorptive capacity. Deeds finds that all three aspects are positively related to entrepreneurial wealth. This means that markets appreciate firms with high R&D-intensities, in late product/service development stages and firms that are involved and embedded in scientific communities.

Wells, Coady and Inge [2003] deal with issues that concern bioentrepreneurship in Australia. They identify reasons for Australia's relatively poor performance in commercializing biotechnology. Major impediments are an inadequate level of commercialization skills, on one hand, and insufficient financial support by the government and the private industry on the other. The traditional "ivory tower" conception of the role that public research institutions take in society is also pointed out as a factor that slows the diffusion of technology towards the industry.

Literature dealing with entrepreneurship is reviewed comprehensively at least by the following two papers. Blanchflower [2004] summarizes works on entrepreneurship that deal with the entrepreneur as a person, mainly in the field of labor economics.

Davidsson, Low and Wright [2001] picture the development of entrepreneurship research within the past decade including works that study entrepreneurship from diverse angles.

The paper proceeds as follows. Section 2 provides a description of the research data as well as the analysis of firm characteristics that are specific to academic spin-offs as compared to other types of biotech SMEs in the Finnish biotechnology industry. Section 3 discusses the findings and Sec. 4 closes the paper with conclusions.

2. Firm Characteristics of Academic Spin-Offs in Biotechnology

2.1. *Data*

The empirical evidence in this paper is based on data originating primarily from the ETLA 2002 survey of biotechnology firms, and the National Board of Patents and Registration of Finland (PRH). The survey data serves as a primary basis for the analysis and consists of information disclosed by the firms surveyed. No data from PRH is used that originates from periods prior to the year 2000. The survey covers the majority of companies operating in the Finnish biotechnology sector. Out of an estimated 120 active biotech companies at the end of 2001, the sample includes 84 companies of which 68 are small or medium-sized.[d]

The companies in the sample are independent businesses, partnerships or subsidiaries of bigger corporations. In the latter two cases the businesses had to be independently responsible business units in order to be included in the sample. If the criteria were not fulfilled, the data were collected from the parent company. No companies being 25 years of age or older met the criteria for inclusion. It has to be pointed out that the majority of firms excluded already for their large size belonged to this age category and the remaining SMEs over 25 years of age could not be included due to the lack of coherent data. Therefore the final sample consists of SMEs that are younger than 25 years of age.

2.2. *Model*

For the purposes of estimating characteristics of entrepreneurial academic spin-offs in the sample, I use a standard probit regression analysis, the results of which are presented in Table 2 in Sec. 2.3. The formal expression of the model takes the following form:

$$D_i = c + \alpha I_i + \beta C_i + \varepsilon_i. \tag{1}$$

[d]The sample is smaller than the population for the following reasons. The existence of a number of companies was unknown prior to the execution of the survey so that 116 companies were initially contacted. The contacts were based on the member list of the Finnish Bioindustries Association that serves as a central organization for the Finnish biotechnology sector. One of the companies was tracked from the Internet. Out of these 116 companies, one was untraceable, 13 refused to respond, 12 were operating in an irrelevant sector, three were not in operation, two had merged with another company and five could not be included due to other reasons. Altogether nine companies were further excluded since they were too large to fit the definition of SMEs. Three companies were excluded because no sensible data was available on them. Another three firms were excluded due to incoherent data. The final sample used in the analysis is thus 65.

D represents the dependent variable, which is a dummy indicating whether a firm is an entrepreneurial academic spin-off as defined in more detail in the next subsection. The constant is represented by the lowercase c in the formula. The independent variables are incorporated into the model by the vector I. The content of the vector is examined more closely later. α is the coefficient of the vector I. C is the control vector representing control dummies and other control variables. β is the coefficient of the vector C. ε is the error term and the subscript index i serves as the firm index.

Dependent variable

The dependent variable of this analysis is a dummy that splits the sample into entrepreneurial academic spin-offs and other biotechnology SMEs. Thus, statistically significant coefficients of independent variables indicate that entrepreneurial academic biotechnology spin-offs differ from other types of biotech SMEs in the sample in respect to the particular independent variable. The dummy is denoted "academic spin-off". It obtains the value "1" only if both of the following criteria are fulfilled: (a) the firm's establishment is based on the results of academic research carried out in universities or other comparable academic research institutions, and (b) the scientist being the originator of the pre-foundation academic research is also the founder or one of the founders of the company. While criterion (a) is the common definition of an academic spin-off, I wanted to narrow down the research target further to encompass only those companies that are based on academic entrepreneurial spirit expressed by the will of an individual scientist to cross the border between the worlds of academia and the industry. This narrow definition excludes firms that, for example, have started operations by acquiring academic research related IPRs from a scientist or organizations like Licentia — A Finnish company specialized in technology transfer between companies, research institutes and universities. It also excludes cases in which the original scientist did not want to abandon her academic career and preferred to pass on the idea of commercializing research results to somebody more willing and eager. By definition, corporate spin-offs and firms that are not spin-offs in the first place are not regarded academic spin-offs.

75% of observations within the sample met criterion (a). After the application of both criteria 67.6% of the sample could be identified as entrepreneurial academic spin-offs.

Independent variables

As this study is explorative in nature and aiming at revealing as many distinctive characteristics of academic biotechnology spin-offs as possible, the choice of independent variables is not restricted by leaning on existing literature alone. In fact, explorative literature focusing on characteristics of academic spin-offs is quite lean and usually has a narrower focus than the underlying study. Instead, all available variables present in the data were included into the initial versions of the model. The final model encompasses only those that show explanatory power. A relatively large number of variables with no statistical significance were excluded from the

final model. Excluded variables include, e.g., turnover indices, growth expectation indicators and locational controls.

Table 1 displays the descriptive statistics of all variables included in the final model. The statistical significance of deviation of means is checked with a two-sample t-test with unequal variances.

Size is expressed via a natural logarithm of the number of personnel employed in the firm. An additional and common approach to capture size effects by using turnover figures has to be neglected since many of the firms do not display positive cash flows yet. Turnover figures do not express the size of operations as much as merely the phase in the life cycle of R&D-intensive firms.

Age is expressed via the natural logarithm of the age of a firm in years. Age was also tested for an exponential distribution with insignificant results.

The biotechnology sector encompasses a variety of sub-sectors ranging from services over food and forestry to pharmaceuticals. The business models applied within those sectors are assumed to vary accordingly, which in turn affects firm characteristics directly. For the purpose of controlling for these effects, I have divided the sector into four sub-sectors. The "*Life sciences*" sub-sector includes firms developing pharmaceuticals, diagnostics and biomaterials. The "*Process industry*" sub-sector incorporates companies active in developing applications in food and feeds, enzymes, agriculture and forestry. "*Services*" comprehends contract R&D and other service activities. Firms not belonging to any of the three sub-sectors are excluded from the analysis as a control group.

Profitability is a measure of economic efficiency and, thus, a performance measure. In this study, profits before interests and taxes (EBIT) serve as the basis for calculating the profitability ratio defined as the share of profits of total turnover. EBIT is used in order to filter out artificial effects that interests, taxes, and especially extraordinary items may have on profits. As many companies display negative profits, the variable is negative in many cases.

Including a variable measuring R&D costs per employee controls for effects of *R&D-intensity*. The usage of more conventional measures like R&D costs per turnover or R&D costs per total costs were not an option due to inconsistencies in the data and because many firms do not display any turnover yet.

Patents serve as a proxy for the innovativeness of companies in the sample and are used for such purposes in a vast amount of literature. The variable is expressed by the *number of patents per employee* a firm has obtained already or applied for. A patent is not double counted if the same patent is obtained in different countries simultaneously.

An *R&D-collaboration* dummy variable is further included into the final model to express whether firms in the sample cooperate with other firms in the same corporation. Other cooperation variables indicating R&D-collaboration relationships with universities, customers, suppliers, competitors and other firms were disregarded due to insignificance.

A dummy variable indicating whether *a firm is a subsidiary* of a corporation is included mainly to control for implicit effects that could interfere with the cooperation variable.

Table 1. Descriptive statistics for included variables.

Variable	Academic spin-off	Obs	Mean	Min/ Max	Std. Err.	t	$P > \|t\|$
Size	0	22	2.589	0.693/4.905	0.2366	1.6155	0.1125
	1	43	2.086	0/4.407	0.2024		
Age	0	22	1.831	0/3.135	0.1697	0.3155	0.7540
	1	43	1.767	0/2.833	0.1127		
Life sciences	0	22	0.455	0/1	0.1087	−0.6034	0.5495
	1	43	0.535	0/1	0.0770		
Process industry	0	22	0.046	0/1	0.0455	−1.8668	0.0666
	1	43	0.186	0/1	0.0600		
Services	0	22	0.273	0/1	0.0972	0.9759	0.3357
	1	43	0.163	0/1	0.0570		
Profitability	0	22	−0.071	−0.600/0.019	0.0311	−1.6374	0.1147
	1	43	−0.019	−0.192/0.050	0.0080		
R&D-intensity	0	22	0.081	0/1.4	0.0341	0.2707	0.7876
	1	43	0.068	0/0.65	0.0324		
Patents/employee	0	22	0.659	0/5.5	0.2633	−1.0210	0.3114
	1	43	1.221	0/20	0.4832		
Is a subsidiary	0	22	0.318	0/1	0.1016	2.5459	0.0173
	1	43	0.047	0/1	0.0325		
Collab. own corp.	0	22	0.409	0/1	0.1073	2.7183	0.0110
	1	43	0.093	0/1	0.0448		
Lead-time protect.	0	22	0.727	0/1	0.0972	−0.5482	0.5867
	1	43	0.791	0/1	0.0628		
Human capital	0	22	0.228	0/1	0.0598	−1.3251	0.1919
	1	43	0.327	0/1	0.0448		
Founder is PO	0	22	0.091	0/1	0.0627	−3.1028	0.0029
	1	43	0.395	0/1	0.0754		
Foreign owners	0	22	0.318	0/1	0.1016	−0.4276	0.6710
	1	43	0.372	0/1	0.0746		
Has licenses	0	22	0.273	0/1	0.0972	1.4347	0.1610
	1	43	0.116	0/1	0.0495		
Export ratio	0	22	39.955	0/100	9.3796	0.2857	0.7766
	1	43	36.721	0/100	6.3367		
Dif. labour	0	22	0.182	0/1	0.0842	−1.2956	0.2011
	1	43	0.326	0/1	0.0723		
Dif. financing	0	22	0.227	0/1	0.0914	−0.2513	0.8027
	1	43	0.256	0/1	0.0673		
Dif. w. bus. idea	0	22	0.091	0/1	0.0627	−1.0956	0.2781
	1	43	0.186	0/1	0.0600		
Dif. experience	0	22	0.091	0/1	0.0627	−1.0956	0.2781
	1	43	0.186	0/1	0.0600		
CEO is PhD	0	22	0.500	0/1	0.1019	0.0870	0.9311
	1	43	0.488	0/1	0.0771		

Another dummy variable is included in the analysis and captures whether firms intentionally and strategically *protect their innovations through lead-time*, the time that the closest competitor lags behind in the development of a competing product/service. Firms that do so, prioritize the speed of R&D processes in order to reap first-mover advantages (e.g. a dominant position on the markets) and thereby discourage competitors from imitating. Other types of protection like patenting and secrecy were also tested for, but were discarded due to statistical insignificance.

The amount of scientific *human capital* residing within a firm is proxied by the share of PhDs in the company's total personnel.

A dummy variable is included to express whether the *original founder or group of founders of the company is still the principal owner* holding a share of equity that provides him with significant power over decisions in the company.

A dummy variable indicating whether *the firm has been able to attract foreign investors* can be a measure of a multitude of aspects, the discussion of which I will defer towards the discussing part of the paper.

Another dummy is used to indicate whether a sample *firm has acquired any licenses* or other kinds of immaterial property rights from other companies that permit the firm to produce products or services as specified by the license/IPR.

The share of sales that is generated through exports is rather high in the biotech sector. An *exports-to-total sales variable* is included in the analysis to test whether academic spin-offs are more globally oriented in terms of markets than other types of biotech SMEs. The ratio is calculated as follows: (Exports/Total sales)*100.

Difficulties to obtain skilled labor represent a clear inhibitor to the growth development of a company. Biotechnology being a highly knowledge intensive business, it is dependent on being able to tap on sources of knowledge and expertise in order to win in the innovation race. Whether the firm experiences difficulties in finding adequately skilled personnel is measured by a dummy in the analysis.

Difficulties in the start-up phase of a company can be argued to constitute stumbling blocks as well. Additionally to the menace of inhibited growth, start-up difficulties might, if known prior to the establishment, deter the entrepreneur from entering in the first place. They are also more critical in the sense that companies are usually more vulnerable to disturbances at the early stage of their life cycles due to limited resources available to respond to such setbacks. In the final model three different types of start-up difficulties are tested, all of which are indicated by a dummy variable: Difficulties obtaining adequate financing, difficulties conceptualizing a clear business idea and difficulties due to the lack of business related experience.

The level of education of the CEO in charge represents a measure of the type of leadership applied in the firm. A dummy splitting CEOs into two categories, PhDs and non-PhDs, acts as a proxy. Generalizing strongly, one could argue that PhDs are more science-oriented than MScs, for example, who in turn are closer to the market in their way of thinking.

2.3. *Results*

The results indicate several characteristics, in which academic spin-offs differ statistically from other types of biotechnology SMEs rejecting the null-hypothesis at the same time. Table 2 summarizes results for all variables included in the final model.

In terms of age, academic spin-offs do differ from other biotechnology SMEs in being slightly younger. The average age of entrepreneurial academic spin-offs is 5.8 years as opposed to an average age of 6.2 years in the case of the rest of biotech SMEs.

Looking at the sector controls, it seems like entrepreneurial academic spin-offs are over represented in life sciences and the process industry as compared to other types of biotech SMEs. In the service sector, on the other hand, they do not distinguish themselves. 53% of academic spin-offs are active in life sciences. Close to 20% are active in the process industry. 15% operate in services. The equivalent figures for the comparison group are 45% for life sciences, 5% for the process industry and 27% for services.

Table 2. Probit regression results with the academic spin-off dummy as dependent variable.

Variables	Coef.	Std. Err.	$P > \|z\|$
Size	−0.920	0.670	0.169
Age	*−1.759	1.023	0.085
Life science	**3.680	1.566	0.019
Process industry	*5.877	3.174	0.064
Services	2.970	2.011	0.140
Profitability ratio	**40.676	19.366	0.036
R&D-intensity	5.371	13.152	0.683
Patents/employee	−0.312	0.416	0.453
Is a subsidiary	−1.371	2.557	0.592
Collabor. w. own corporation	*−3.989	2.317	0.085
Uses lead-time for protection	**3.603	1.782	0.043
Human capital	−1.225	1.535	0.425
Founder is PO	1.874	1.246	0.133
Has foreign owners	**3.624	1.847	0.050
Has acquired licenses	**−2.932	1.435	0.041
Export ratio	−0.017	0.019	0.357
Diffic. obtaining skilled labour	**5.343	2.500	0.033
Diffic. obtaining financing	**4.847	2.393	0.043
Diffic. w. business idea	**11.712	5.706	0.040
Diffic. due lack of experience	−2.881	2.499	0.249
CEO is Ph.D.	**−3.556	1.577	0.024
Constant	1.560	2.487	0.531

N = 65
Log likelihood = −13.6746
LR chi2(21) = 55.8500
Prob > chi2 = 0.0001
Pseudo R2 = 0.6713
Asterisk labels (*) stand for level of statistical risk of rejecting the null hypothesis erroneously. (*) 10% , (**) 5% , (***) 1% risk level.

It appears that academic spin-offs perform better in terms of profitability. They make relatively smaller losses than other types of biotechnology SMEs. Academic spin-offs show losses in the scale of 19% of sales. In the control group losses count for 71% of sales.

Academic spin-offs cooperate with firms within the same corporation significantly less than firms in the control group. Only 9% of academic spin-offs have cooperation relationships in R&D within the same corporation, while 41% of firms in the control group cooperate in such a way. This finding is robust even after introducing a dummy indicating whether a firm is a subsidiary, which excludes the explanation that academic spin-offs do cooperate less within the corporation simply because a majority of them are independent businesses and are, thus, no part of a corporation in the first place. Cooperative relationships with academia, customers, suppliers, competitors and other firms were encountered in both groups to an extent that no significant differences can be pointed out by the means of the regression analysis, although looking at plain figures might tell a different story. Table 3 sums up the figures.

Academic spin-offs resort to lead-time as means to protect innovations more often than other types of biotech SMEs. 79% of academic spin-offs answered to use this kind of strategy whereas 73% of the control group gave the same answer. As already stated above, other instruments of protection like secrecy and patenting could not be identified to be used more by either of the groups in any model run.

Academic spin-offs are more often owned primarily by the original founder than firms of the control group. Such a principal owner is defined as being the single largest stock owner measured by the total number of votes. In 40% of all academic spin-offs in the sample, the founder was the principal owner. Just 9% of the control group was primarily owned by the founder.

Academic spin-offs have more often foreign owners than firms in the control group. 37% of academic spin-off companies in the sample have foreign owners, whereas the percentage for control group firms is 32. The coefficient is positive and significant at the 5% level.

Buying rights to produce products or services developed by other organizations is less preferred among academic spin-offs than in the control group. 12% of academic spin-offs have acquired such rights whereas among firms in the control group 27% have done so. The coefficient is negative and significant at the 5% level.

Academic spin-offs are more often plagued by difficulties to obtain skilled labor needed for operations. A third of firms reported to experience such difficulties. In the control group only 18% struggled with the same problem. The coefficient is significant at the 5% level.

Table 3. R&D cooperation agreements in percentages of firms.

Cooperation with:	Own corporation	Competitors	Customers	Suppliers	Other firms	Academia
Academic spin-offs (%)	9	17	52	31	43	87
Other (%)	41	45	77	50	55	77

Academic spin-offs experience also more often difficulties in the start-up phase than do firms of the control group. 26% revealed that there were problems related to inadequate financing. 19% fought problems related to the lack of a clear business idea. Relevant figures for the control group are 23% and 9% respectively.

According to the regression results, a CEO having a PhD degree less often directs academic spin-offs than firms in the control group. The coefficient of the dummy is statistically significant at the 5% level. Although the finding is counter-intuitive, the dummy serves as a control.

3. Discussion

3.1. *On the findings*

When looking at the results concerning R&D-intensities and R&D-productivity measures, one cannot tell a difference between entrepreneurial academic spin-offs and other types of biotechnology SMEs. In my opinion the finding is rather intuitive. Firms competing in biotechnology must keep up with each other in terms of R&D efforts as future revenues depend greatly on the outcome of patent races that are highly competitive and are played globally. Loosing a race could render invested capital worthless and mean the end of the company, especially in the case of young enterprises that have only a limited project portfolio over which to spread the risk of failure. This applies to all biotechnology firms regardless of their origin, academic or not. With all biotech SMEs being highly R&D-intensive, the relative differences in R&D activity measures between the two groups might be too small to be observed in a small sample.

Recalling the above reviewed paper by Deeds [2001], this would imply that academic spin-offs cannot be expected to create higher entrepreneurial value (Market Value Added) than other types of biotech SMEs, since they do not display higher R&D-intensities or technological capabilities.

However, a word of caution should be uttered concerning the findings on R&D-productivity. A problem causing potential distortions is the measure used for R&D-productivity, patents per employee. Patents do not come automatically with innovation and do not necessarily reflect the number of innovations produced within a company. To obtain a patent, the firm or individual has to have knowledge on what criteria the innovation has to meet before it stands a chance of being patented, how to initiate the patent application process, to what extent a patent protects the innovation, and, most importantly, what to apply for and how to formulate the application in order to obtain maximum protection or to succeed in the application in the first place. Additionally and not least significantly, patenting requires considerable amounts of money to be obtained and maintained. These requirements multiply when going global, as is the case in biotechnology. This kind of expert knowledge is often not existent in young and small companies that have a more scientific background and are run by people with an academic origin. On the other hand, such knowledge can be expected to be resident in corporate spin-offs, for example, that come from a commercial background right from the beginning. Also

access to expert advice and financing for patenting through readily established networks can be expected to exist more often in this kind of organizations. This being said, it might be that the R&D-productivity of academic spin-offs is not captured properly and it may seem to be lower than it actually is.

The above intuition might also provide an answer to the question why entrepreneurial academic spin-offs revert more often to lead-time as a means of protecting innovation than firms in the control group do. It is cheaper and does not require the hassle of the patent application process. This being said, it would be interesting to find an answer to the implicit question, whether academic spin-offs are in fact more productive in terms of R&D than other types of firms in the Finnish biotech sector. If the above discussion holds true, then it actually is the case, since academic spin-offs in the sample perform just as well as the control group measured by the number of patents per employee even with constraints in access to resources and knowledge on patenting.

The finding that academic spin-offs operate more often in life sciences and the process industry is fairly intuitive in the sense that these sub-sectors are far more science-based than services, and current technologies represent usually the forefront of technological research and development. Nevertheless, thinking of resources necessary for developing avant-garde products or services and taking them to the market (that a large part of academic spin-offs clearly lack) it would be more plausible to see older and larger firms to be over represented in the life science and process industry sub-sectors as compared to academic spin-offs. As Smith and Fleck [1988] state, in the US it is a common entry strategy of young, resourceless biotech firms to provide different kinds of research services in the initial post-foundation phases to create turnover that can then be directed towards own R&D that aims at breakthroughs. It is a natural way of utilizing valuable and expensive human capital existing in the company right from the start to enhance independence from outside financing and avoid complications related to that. So, why do we not find young and small Finnish academic spin-offs to be relatively more active in the service sub-sector instead of life sciences and the process industry as indicated by the results?

The answer, in my opinion, is rather straightforward. The prominent way of thinking in Finnish academic biotechnology SMEs is extremely technology driven, not business driven. Many academic entrepreneurs apparently establish the firm for the love of the technology, business coming second. In their view it is more important to enhance and work on the technology, their "child", than to think about viable business solutions and ways of establishing a vital revenue stream that would bring a higher degree of independence with it. The firm is seen as a means to apply for further funding (for example Tekes, the National Technology Agency, does not fund individuals but companies) that enables the advanced development of the particular technology. According to expert interviews,[e] some founder-scientists sometimes even hamper the growth and development of their company as a business and do not want to hand over the lead to more business-skilled individuals, because

[e]Personnel in leading position at a Finnish public organization providing funding to Finnish companies with the biotechnology sector being a major target of investments.

they prioritize the development of the technology and their personal involvement in it over the well-being of the company. It is a central concern at conferences and seminars dealing with economic aspects of Finnish biotechnology, that there is a lack of business-related skills employed in the sector that impedes not only the growth of but makes Finnish biotechnology vulnerable to global competition, where the business logic and the requirements set by that are far better understood than in Finland. The finding that academic spin-offs suffer from difficulties related to an unclear business plan at the start-up phase underlines the above discussion empirically.

Just realizing the problem is by far not enough. In fact, many firms are aware of the problem and some even want to improve the situation. Venture capitalists even demand the employment of highly business-skilled people that are experts in business administration and have substantial experience in the field before injecting risk capital into a biotech company. So what stands in the way of improvement? The problem is a structural one. A large pool of skilled individuals with relevant background which to recruit from is simply non-existent in Finland. Finland does not look back at a strong and traditional history of industrial evolution in pharmaceuticals or any other relevant field that could spawn experienced leaders like, e.g. Sweden or the UK. In fact, at present venture capitalists have to look abroad for occupying leading positions with the right individuals in their portfolio firms. But even this is extremely difficult not least due to an uncompetitive income tax regime prevalent in Finland.

Problems of finding adequately skilled personnel do not concern business expertise only. Entrepreneurial academic spin-offs are hard pressed with finding personnel for research activities as well. This is somewhat surprising, since it is a common consensus that the level and quantity of biotech research relevant know-how as well as the amount of educated people with the appropriate skills in Finland is fairly high. There should be no supply shortage of qualified potential recruits. I believe the dilemma has its roots in the perceivably traditional role of universities and the world of academia as a whole that is prevalent throughout Europe.

The academia's perception of itself still, and unfortunately, resembles that of the famous "ivory tower". Interviews with experts[f] actively involved in the world of academic research revealed that commercialization of research and the business world as such are often perceived by academics as "filthy", "greedy" and "dishonorable". The exposure of scientific research to commerciality is perceived to distort the one and only ultimate purpose of science, namely the quest for truth. Scientists leaving the academia are quickly marked as mavericks and traitors of the cause and are put in negative light. In fear of being branded and not being able to return to academia in case of failure in the business world, talented and potential academic scientists with promising academic careers are reluctant to become entrepreneurs or be recruited to work in a commercial company. Apparent risks are too high. This is a real obstacle that cannot be overcome easily. An improvement would require a major change in attitudes and institutional roles throughout the society as a whole

[f]Medical Doctor actively conducting research in the field of neurology.

questioning the positions and power of individuals, which most assuredly will cause inertia and friction in the process of change. This line of argumentation is very similar to that of Wells, Coady and Inge [2003].

Another explanation for problems with the availability of skilled labor is likewise related to the customs of traditional Finnish academia. The entrepreneurial scientist who has freshly started up a firm (a) does probably not understand why they should pay an employee more than this scientist earned at the university or another research institute for the same work he would be conducting at the company and (b) does not necessarily have the capital that it takes to lure personnel from the academia to work for him and compensate them for all the risks explained above.

There are still more impediments that academic spin-offs have to struggle with. According to the results they had problems with acquiring sufficient funding at the start-up stage of their life cycle. Funding shortages or delays stall the momentum of the commercialization process and add to the business risk. According to expert interviews at a governmental finance institution, the present times and the near future look even worse for academic entrepreneurs dreaming of starting-up their own biotech business.

When the ICT-bubble burst at its peak in 2001, the capital financing for new start-ups became difficult. Before that time biotechnology firms were heading towards public capital markets at very early development stages already accelerated by great expectations as high technology related businesses experienced a boom. Exit channels seemed open from the perspective of investors and investment periods were expected to be between two and four years long. After 2001 a quick exit is not viable anymore. With deteriorated expectations market values of early stage companies became extremely low. Investors invest only in firms that are in a late development stage, close to the markets, and are preferably making profits already. The funds of these investors cannot bear to wait as long as it would take to bring an early stage biotech company close enough to the market to reap high enough returns on invested capital. The timeframe from establishment to exit is three times longer than prior to 2001. The only institution that has a policy to provide capital to early stage companies in Finland nowadays is Sitra. But even Sitra is unable to invest in new start-ups as it cannot free capital bound to the existing portfolio. A glimpse of hope is to be expected from a new instrument announced by Tekes, which is aimed at financing firms at the seed stage already. No exact specifications of that instrument are published yet. Tekes also continues to provide capital loans to companies, which has been a rather successful financing tool from the late nineties onwards.

The lack of outside financing is further underlined by the finding that the original founder of the company still holds the sole principal owner position in entrepreneurial academic spin-offs. In over 40% of cases it is the founding scientist that owns the majority of voting rights. The equivalent figure for other types of biotech SMEs is 9%. When the flow of outside equity financing is constraint the implicit consequence on the balance sheet is a high share of equity owned by insiders, here the original founder. It has to be pointed out at this point that the capital and regular loans as well as subsidies provided by Tekes do not constitute an equity

item on the balance sheet although capital loans have many traits in common with equity otherwise. A complementary reasoning is the above mentioned reluctance on part of original founders to hand over the control of the company to outsiders as it could jeopardize the founder's right to work on the technology and divert the purpose of the company towards less important priorities from the founder's point of view. Additionally, some founders are just happy with the income they obtain through direct research support schemes and do not even plan to go to financial markets with plans of expansion on their minds.

The relatively small size and struggles with financing are reflected in the profitability ratio of entrepreneurial academic spin-offs; they run a smaller deficit in average than firms in the control group. An average profitability ratio of ca. -20% as opposed to ca. -70% of other types of firms indicates not only scale effects stemming from a relatively smaller size of operations in terms of staff employed but also cautious and risk-adverse behavior under resource constraints and a present threat of running out of funds. I assume that as the firm grows and is able to access better financing sources the degree of risk-adverse behavior decreases, as the fear of bankruptcy is not as immediate anymore. In such a case a relatively higher portion of funds is directed towards R&D causing higher losses, assuming that revenues do not increase proportionally to the increase in size simultaneously. This assumption is justified as long as the firm is still in the development phase of an initial product/service and has not entered markets yet.

Small-scale operations and budget constraints also negatively affect the ability to purchase licenses from third parties that would endow the company with rights to market products or services developed by a third party in order to generate initial cash flows. Faint resources are focused on the particular research, which the company has initially been established for. Only 11% of academic spin-offs have acquired licenses from a third party as opposed to 27% of firms in the control group.

The reason for the lack of collaboration between academic-spin-offs and companies in the same corporation seems apparent on the first sight. The vast majority of academic spin-offs (44 out of 46 firms in the sample) are independent in the sense that they are no subsidiaries to another company as already indicated by a high ownership share of the original founder. Nevertheless, even after controlling for this by inserting a dummy identifying whether firms are subsidiaries, the result remains significant. Not being a subsidiary does not exclude the possibility that academic spin-offs are parent companies themselves and have spun out corporate spin-offs during the course of their existence nor that they have merged with other companies out of strategic reasons. The fact that five of 46 entrepreneurial academic spin-offs in the sample, three more than there are academic subsidiaries, do collaborate within the same corporation speaks in favor of this theory. Reasons for the relatively inactive cooperation could include the difficulty to transfer relevant tacit knowledge across firm boundaries in an efficient way as well as the lack of business-oriented thinking that emphasizes the importance of cooperation for successful commercialization.

As already pointed out in Sec. 2.3, cooperation patterns with other stakeholders like customers, competitors and suppliers do not differ significantly in the regression analysis. Nevertheless, simple means of cooperation measures (Table 3) show that a relatively smaller share of entrepreneurial academic spin-offs does cooperate with other interested parties except the academia. According to Shan, Walter and Kogut [1994], Nilsson [2001] and Powell [1998] this is a threatening finding, since interaction is identified as a prerequisite to commercial success that Finnish biotechnology SMEs obviously seem to lack. This seems to be another indication of the void in business related expertise in academic biotechnology spin-offs in Finland. Strategic partnering and networking is one of the major elements in the struggle for competitiveness allowing partners to focus on their particular core competencies cutting inefficiencies to the minimum at the same time. Academic spin-offs seem to be unaware of this fact. Isolation and a too technology-focused attitude compromise the ability of firms to identify and capture emerging opportunities, be they technological or commercial, in the absence of a supportive and complementary network.

The insignificance of the difference in export ratios is explained by the fact that the markets for biotechnology are global. Domestic markets are just too small to build a viable business on. Thus, all Finnish biotech companies have the imperative to aim at foreign markets right from the beginning if they want to secure growth and survival in the long run.

3.2. *On the limitations of the study*

The limitations of the study are mainly related to the technical implementation of the statistical analysis.

In contrast to the conventional purpose of the regression analysis as an analytical tool, the present study is not applying it with the intention to explain what factors led to or influenced the foundation of academic spin-offs. Instead, the primary aim is to explore the present, static state of academic biotechnology spin-offs by exploring firm characteristics represented by the independent variables. In this sense the dependent variable is interpreted as a classification of the firm that distinguishes it from other types of companies rather than an event. In this setting the regression analysis is used as a tool to reveal affiliations with other firm characteristics making the study more explorative than explanatory in nature. The reason for choosing a regression over, e.g. t-tests, as the analytical method lies in its power to control for simultaneous effects that independent variables might have on the dependent one. Possible reverse causalities between the dependent and independent variables pose a potential area for future research that would greatly benefit from time-series data.

Another limitation relates to the ratio of the number of cases and independent variables. Statistical results in a setting with a small number of cases are usually more unstable than in a setting with abundant cases. In the present study this is true to the extent that the final model is slightly sensitive to the exclusion of some single variables. However, sensitivity analyses show that the sensitivity is rather small. Exclusion or inclusion of some variables might result in a slight increase of the p-value of variables already in the model but affect their statistical significance

only marginally. The exclusion never resulted in a change of fore signs of coefficients that could have been an indication of multicollinearity among the independent variables. Throughout the iteration of alternative models the variables of the final model showed consistent and robust behavior justifying their inclusion.

4. Conclusions

In conclusion one can say that Finnish entrepreneurial academic spin-offs are at a relative disadvantage as compared to other types of biotechnology SMEs. Hit more often by financial difficulties at start-up, being unable to attract skilled people, and, most unfortunately, lacking the vital strategic sense and skills for transforming research into a thriving business through cooperation and a market oriented approach, academic spin-offs are facing major impediments to successful growth. Probably the most critical challenge is to shift the focus of companies away from a strongly technology-oriented path towards a more extrovert and market-oriented one, where the particular technologies should be evaluated less in terms of technological prowess but more in terms of market potential. Only tapping into the suction of market demand will constitute a viable strategy that brings growth and long-term success with it. A purely technology driven company having the creation of avant-garde technology as the Raison D'être alone, is obsolete and without purpose on markets. It will not last. This implies a major change in modes of thinking in the minds of today's scientists and an active expansion of support and educational services that aim at bringing that message into the hermetically sealed laboratories. The establishment of biotech centers in Finland has been a welcomed first step, since firms are able to establish cooperative inter-firm links with less effort and utilize spillovers. Now, one should make sure that services at these centers encompass more than just facilities. Education in the processes of commercialization, strategic thinking, project and technology management as well as immaterial property rights is anxiously needed.

The impediments do not rise exclusively from inabilities and lack of skills on part of academic spin-offs. A very traditional and detached perception and definition of the academia's role within society, high income tax regimes, and a still underdeveloped market for equity in Finland contribute unfavorably to the conditions academic spin-offs operate in. These are factors that the companies themselves cannot address properly and should be discussed on the national level. Currently the Finnish biotech sector is under pressure to show hard evidence of success in order to justify past and future public investments to the sector. Instead of being just impatient one should sit down and come up with solutions that address the structural and cultural issues discussed above, first. These are issues that only the public as a whole can have an influence on. Only then will public investments into the sector be productive.

The change from a technology driven organization towards a business oriented one implies managerial challenges that need to be addressed on the firm level. Probably the most urgent issue to tackle is the apparent deficit in business skills. The fastest way to cope with the problem, assumed first that there is a will to do so, is probably the recruitment of people that are already experienced in leading

and managing R&D intensive ventures. As Finland faces a relatively small pool of such people with a background in fields relevant to biotechnology (pharmaceuticals, diagnostics etc.), one might look beyond biotechnology itself into sectors that are comparably R&D- and technology intensive and already flourishing. In the Finnish case the strongest candidate is the ICT sector that, led by Nokia, has risen to be one of the three main pillars supporting the economy in the last 15 years. Sitra, a Finnish public organization providing venture capital, has already reported success stories, according to which former ICT managers have been successfully integrated into biotechnology companies with positive results.

Another critical challenge is the development of parallel business models that help the company survive the financial gaps in the early stages of business. Surely, a company's founder usually has a clear vision of where he wants to get in the long-run but getting there, especially in the biotechnology business, takes a long time, a deep pocket and might require stepping off the beaten path by exploring alternative business models that utilize existing assets of the company to provide revenues necessary to keep the venture alive on its way to the ultimate goal. Certainly, this requires out-of-the-box thinking and patience, but it is necessary in the times of insufficient financing provided by financial markets.

Finally, poor inter-organizational collaboration of academic spin-offs is a threat to their competitiveness. A well organized and managed network of partners might result in synergy effects and leaner cost structures as well as an enhanced capability to capture emerging opportunities as reaction times are faster and joint resources can be leveraged efficiently. Also R&D efforts benefit from collaboration as joining knowledge from multiple sources might spawn innovative ideas to problems that could not be solved in isolation. Certainly, the danger of unwanted knowledge spillovers is existent in every collaborative arrangement, but if handled with care, the benefits outweigh the threat by far.

The study opens diverse avenues for future research. Firstly, for a deeper understanding of the influence of national innovation systems, cultural environments and other external country-specific factors on academic entrepreneurship in biotechnology, studies on other emerging biotechnology clusters are needed. Comparisons could not be drawn only between countries but also between different industrial sectors. Secondly, research on the viability of alternative, revenue creating business models for biotechnology ventures is of great value to the discussion dealing with issues of commercializing such research, as financial markets at present seem to be reluctant to invest into research-intensive businesses after the burst of the IT-bubble. More precisely, it would be interesting to see *how* biotechnology start-ups could utilise partnerships to access resources needed at particular growth phases. Finally, with biotechnology being a knowledge-intensive business, the interdisciplinary application of the knowledge management literature on aspects of economics of biotechnology might enhance the quality of studies and be an innovative approach taking the nature of biotechnology into consideration.

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Biography

Antti-Jussi Tahvanainen is a research economist at ETLA, the Research Institute of the Finnish Economy. With a background in technology management and politics, his current research focuses on economics and managerial perspectives of biotechnology. His prior work deals mainly with financial structures, knowledge management issues and aspects of academic entrepreneurship in the biotechnology industry.

Appendix 4. Measuring Intellectual Capital and Sources of Equity Financing

Hermans, R. – Kulvik, M. (2004). Measuring intellectual capital and sources of equity financing – value platform perspective within the Finnish bio-pharmaceutical industry. *International Journal of Learning and Intellectual Capital*, vol. 1, no. 3, 282-303.

Measuring intellectual capital and sources of equity financing – value platform perspective within the Finnish biopharmaceutical industry

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Abstract: The aim of this study is to create a theoretically derived basis for measuring intellectual capital within the Finnish biopharmaceutical industry, and to relate these measures to ownership structures. Our empirical model employs survey data from small and medium-sized Finnish biopharmaceutical companies. The sources of equity financing are identified and the means of measuring Intellectual Capital (IC) in the value platform framework is created. Various sources of financing are related to the intellectual capital and other characteristic features of these companies. The biotechnology company owned by another firm is distinctive, corresponding to different strategic functions designated to the company by the owner firm. The largest investor group, venture capital companies, seem to prefer a well-balanced combination of intellectual capital. The other owner groups showed among themselves a rather similar pattern of investment preferences.

Keywords: biotechnology; capital structure; intellectual capital; knowledge management.

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Martti Kulvik is a Medical Doctor and a Research Scientist at the neurological department of the Helsinki University Central Hospital. He has completed an MBA degree in biotechnology management, and he has consulted young biotechnology companies. In addition to clinical work he has been involved in

multidisciplinary research projects, including gene therapy and boron neutron capture therapy. He has authored and coauthored several medical journal articles, and also articles related to biotechnology management.

1 Introduction

1.1 Background

The biotechnology sector is expected to create a new phase of technological development that will have a pronounced impact on economic growth. Several overviews of the Finnish biotechnology industry have been made (for further references see Kuusi, 2001; Schienstock and Tulkki, 2001; Hermans and Luukkonen, 2002). ETLA[1] carried out a survey of biotechnology companies in spring 2002. This study measures intellectual capital of biopharmaceutical companies and estimates capital structures related to intellectual capital holdings.

The number of biotechnology companies has grown sharply. In the end of 2001, there were about 120 biotechnology companies in Finland. This is almost 7% of the entire number of biotechnology companies in the European Union (EU) (Kuusi, 2001) – a considerable amount if we contrast it to Finland's population of five million, about 1.3% of the EU population in 2003. Finland can be considered as a biotechnology-intensive country. However, Finnish companies are limited in their size and ability to exploit their market potential: more than 100 of the Finnish companies were small or medium-sized.[2]

Most of the Finnish biotechnology business activities have a connection to healthcare applications. Almost 60% of the small and medium-sized biotechnology companies are related to pharmaceutical industry or research. The pharmaceutical markets hold high growth expectations due to the development of medical research and the ageing of the population.

However, the risks related to drug development are also high due to a particularly risky research and development (R&D) process as well as the complex marketing in a global scheme. This induces needs for pharmaceutical giant companies to control risk through external collaboration in R&D activities. Thus, many giant pharmaceutical companies have outsourced a part of their biotechnology-based R&D activities to small research-intensive biotechnology companies.

Small biotechnology companies can survive amidst pharmaceutical multinationals either:

- through selling straightforwardly some specific research services
- by developing drugs of their own.

In the first case, the biotechnology company receives positive cash flows even at the onset of the company. In the second case, the company needs external finance to carry out the drug development process to a later stage and thereafter either license or sell its intellectual property rights (IPR) to pharmaceutical companies, or, its owners can sell their equity to other investors, such as another company with sufficient resources to finish the development process and perform the market launch.

1.2 Aims and structure of the study

The aim of our study is to create a basis for measuring intellectual capital as a theoretically based indicator for value creation potential in knowledge-intensive companies. The distribution of the measured intellectual capital in biopharmaceutical companies is mirrored against the investment allocations of distinct investor groups. Investors strive to allocate their funds to projects with highest value creation potential in line with their own strategy and risk profile. If the measured intellectual capital reflects the desired quality of a company, the investments of the investor groups should be reflected in the measured intellectual capital profiles.

The study was further divided into three subgoals:

1 To identify the sources of equity financing in Finnish biopharmaceutical companies.

2 To create a means of measuring Intellectual Capital (IC) in the value platform framework.

3 To depict how various sources of financing are related to the intellectual capital and other characteristic features of these companies.

In order to fulfil the first aim, the sources of equity financing and capital structure were evaluated with respect to the companies' age and size as well as their research intensity. The second aim was achieved by forming principal components from indicators, which depict the three IC categories. In order to accomplish the third aim, principal component analysis was used to evaluate how different sources and types of financing are related to the companies' intangible assets.

This paper is organised as follows. After the introduction, Section 2 provides a theoretical overview and definitions of the value platform framework on intellectual capital. Section 3 describes our empirical data on small and medium-sized biopharmaceutical companies. The capital structures and sources of equity financing are mirrored against the general characteristics of the companies. Section 4 depicts IC components in the context of value platform and relates the findings of the principal component analysis of intellectual capital to the sources of equity financing. Section 5 concludes the results of the study.

1.3 The survey data

The data used in this study are derived from a survey performed by ETLA. The survey covers financial and business-related information on 84 companies operating in the biotechnology sector. An overview of the data is presented by Hermans and Luukkonen, (2002). The capital structures of all biotechnology small and medium enterprises (SMEs) are described in Hermans and Tahvanainen (2002), and the intellectual capital of the firms are related to their anticipated sales in Hermans and Kauranen (2003).

ETLA's survey was carried out in early 2002, and its information is based primarily on the situation at the end of 2001. The information from financial statements has been crosschecked with the trade register of the National Board of Patents and Registration of Finland. We selected 42 small and medium-sized firms which either categorised themselves as belonging to the pharmaceutical industry, or whose clients or subcontractors are in the pharmaceutical industry. The entire population of biopharmaceutical SMEs is estimated to be about 60. There were 38 companies out of the

initial 42 companies in the final principal component analysis. Three of the companies were excluded because they lacked some variables on intellectual capital; one company was regarded as an outlier as it represented nearly half of all the equity in Finnish biopharmaceutical SMEs.

We have at our disposal a cross-section data from the end of 2001. However, conclusions regarding cause-effect relationships between intellectual capital and equity financing would require time series data. The given data does not allow, for example, an analysis of whether a well-balanced combination of intellectual capital has attracted equity investors, or whether they have, as to year-end 2001, developed the companies into their preferred combination of intellectual capital.

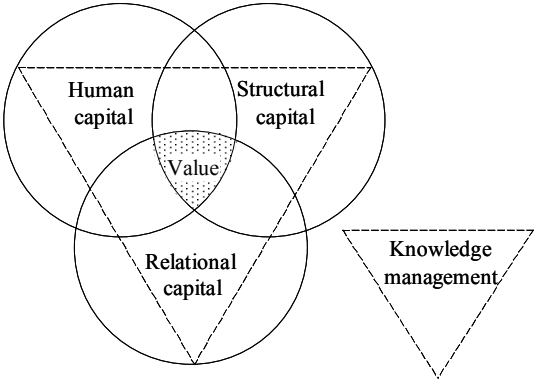
2 Theoretical framework

2.1 The value platform model

Commercialisation of products by biopharmaceutical companies is geared primarily toward a rather distant future, in contrast with other SMEs (Appendix, Table A1). Active research is ordinarily anticipated to generate expectations of future revenues. However, the emphasis on commercialisation geared toward a distant future increases the business risks, which in turn increase the yield requirements of investors. Given the revenue expectations of entrepreneurs and the yield requirements of investors, it is understandable that 86% of the biopharmaceutical companies expect their turnover to rise over the next five years at an average annual rate exceeding 10%. In contrast, only about 20% of all SMEs expect turnover to grow faster than 10% per annum.

A company's present intellectual capital can be regarded as a valuable source for estimating future commercial opportunities (Edvinsson and Malone, 1997; Sveiby, 1997; Stewart, 1997). Figure 1 presents the value platform definition of intellectual capital and the value of the company (Edvinsson and Malone, 1997). The value is created by a balanced and strategically meaningful management of three categories of intellectual capital.

Figure 1 Intellectual capital and knowledge management, modified from Edvinsson and Malone (1997)



The first category is human capital[3] composed of the skills and competencies of the company's labour. The second category is structural capital, which signifies the company's ability to organise its activities in such a way that the tacit knowledge of its human capital can be converted into intellectual property rights owned by the company.[4] The third category is relational capital, which stresses the importance of external networks, for example, with customers and other partners.

It is the close interaction between these three categories of intellectual capital that enables a company to create value from its business activities. This is achieved by a skilful knowledge management: a well-balanced combination of human capital, structural capital, and relational capital.

2.2 Theory-based variables

Human capital comprises the knowledge of the personnel. Biotechnology is a science-based sector where knowledge management is given more emphasis than in many other sectors. This study measures human capital with four variables:

1 The ratio of doctors-to-personnel depicts the company's scientific competence.

2 The business experience of the CEO in years measures the business knowledge of the management.

3 The marketing expertise is measured by an indicator variable, which gets values zero and one. The variable gets the value of one if the company employs a full-time expertise in marketing, and zero otherwise.

4 The industrial expertise is valued similarly, according to the company's statement.

Structural capital includes the company's internal organisational structures and organisation of activities, whereby it seeks to use human capital efficiently. In this connection, structural capital is measured using the following four variables:

1 R&D intensity is estimated by the ratio of R&D expenditures to total costs.

2 The ratio of patent applications to patents describes patent creation intensity.

3 The sum of patent applications and patents divided by number of personnel approximates innovation intensity.

4 The age of the company (measured in years) depicts different stages of the company and thus its maturing strategy. In biopharmaceutical companies it can also relate in some extent to the different phases in drug development.

Relational capital is comprised of the company's external relationships. For example, without customers the company is not viable, even if the activities of its highly educated personnel are otherwise well organised. Relational capital is measured using three groups of variables:

1 Dependency on (principal) customers and suppliers:

- Customer-dependency: if the company sells over one-third to its principal, then this indicator variable gets a value of one, otherwise it gets a value of zero.

- Supplier-dependency: if the company purchases over one-third of the total purchases from its principal subcontractor, the variable gets a value of one, and otherwise it is zero.

2 Amount of direct and indirect governmental support. The earnings expectations of biopharmaceutical companies are often several years away; in such companies sufficient R&D activities and research networks provide the critical mass for future success. Almost all biopharmaceutical companies engage in collaboration with some domestic research institutions or universities. This study evaluates:

- How much of a company's total R&D expenditures is financed by government institutions (direct support)?
- How many percent out of the governmental finance is used to pay for university collaboration (indirect support)?

3 Nominal credibility. Is the auditing of the company handled by one of the big five auditing firms?

3 Equity financing

3.1 Sources of equity financing

Hyytinen and Pajarinen (2002) used branch-specific data on Finnish companies and estimated the structure of Finnish SMEs by weighting the sample by industrial branches. In this study, the sources of equity financing were derived following a procedure presented earlier in Hermans and Tahvanainen (2002), Tahvanainen (2003), and Hermans (2003). Appendix 1 compares the biopharmaceutical industry with the entire SME sector.

We used weighted values of the equity capital, where the weights were formed by a simple index, which measured the ratio of total population to sample population in three age groups. The number of companies and the age of the entire population were compared to the number of companies in the sample. The weights were obtained as follows:

$$\frac{n_{total(t)}}{n_{sample(t)}}$$

The terms n_{total} and n_{sample} denote the number of companies in the total population and the sample, respectively. Term t denotes the three groups (t = 1, 2, 3) in order of age. Group 1 consists of companies founded in 1997–2001, Group 2 is comprised of companies founded in 1991–1996, and Group 3 includes companies older than this. Using the weights described above we could estimate the capital structure for the entire population of biopharmaceutical companies. It was assumed that companies that are not in our survey database are similar on average to their counterparts in the database.

This section investigates the capital structure of the Finnish biopharmaceutical companies. Almost half of the companies made a loss in 2001, the fiscal period evaluated. Realised losses reduce the amount of visible equity in the balance sheet. However, since this study assesses how much has been invested in the companies in the form of equity and capital loans as well as other forms of debt, the realised profits or

losses are not taken into account and thus do not interfere with our results. Consequently, the capital structure presented in Table 1 does not correspond to the figures directly obtainable from the balance sheets.

Table 1 Capital structure by age and size of biopharmaceutical companies

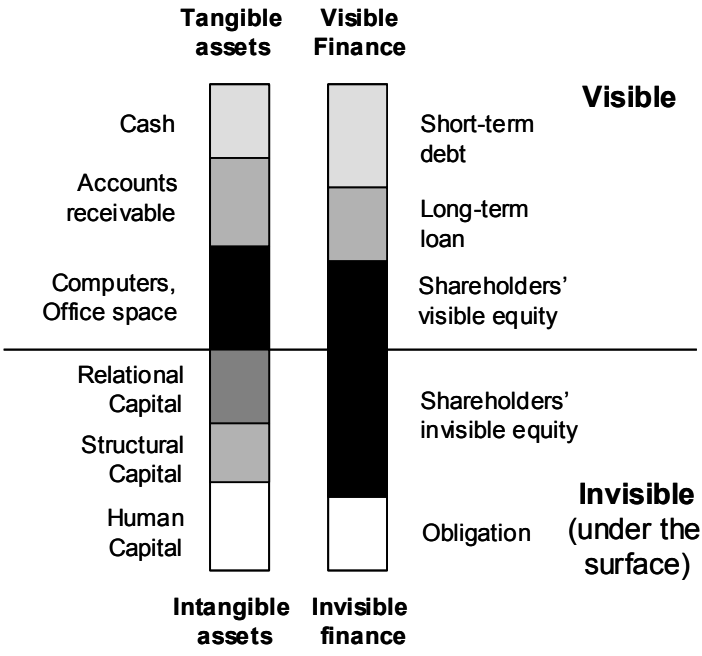
	Equity	*Capital loans*	*Loans*	*Total financing (million euro)*
Total	71%	18%	11%	225
0–4 years	77%	11%	12%	135
5–8 years	71%	28%	1%	59
9–24 years	41.4%	33.6%	25%	31
Small	50%	36%	14%	21
Large	73%	16%	11%	204

Equity financing is a prominent form of financing in all biopharmaceutical companies (Table 1). Capital loans are also a considerable financing instrument for the smallest and the oldest companies. Capital loans are judicially considered as a part of the total equity in the balance sheet. The capital loans supplied to biopharmaceutical companies have come almost entirely from the public sector. The largest supplier of capital loans is Tekes,[5] which accounts for over 80% of the capital loans granted to this sector. Tekes provides also other loans as well as R&D support. Biopharmaceutical companies have relatively low levels of indebtedness. Loans account for 11% of total financing on average. Loan financing, which is classified as a liability, is relatively higher in older companies, a fourth of whose capital comes from loans.[6]

3.2 Visible and invisible equity

In order to further elaborate on the capital structure of a company we utilise Sveiby's (1997) setting of "the balance sheet of knowledge organisation" (Figure 2). Shareholders' invisible equity can be defined as the difference between the continuously changing market capitalisation of the company, and the nominal value of equity in the visible balance sheet. Shareholders' invisible equity can be valuated if the company is listed in a stock exchange or when an unlisted company is sold.

Figure 2 The balance sheet of knowledge organisation (Sveiby, 1997)



The book value of a company is often below its market value as determined, for example, on the financial markets (Hall, 2001). Investors seek to make investment decisions based on expectations of future returns. The future return expectations regarding a company can be assessed on the basis of financial statements and intangible assets at disposal in the company. The intangible assets of a company are seldom booked at full value on the official balance sheet. In a broad sense the whole intellectual capital of a company can be regarded as an intangible asset (Edvinsson and Malone, 1997; Sveiby, 1997). A company's intellectual capital can be divided into human capital, structural capital, and relational capital (e.g. Edvinsson and Malone (1997)).

The company is conventionally valuated according to its net present value (NPV), based on future cash flows or profits. Tangible assets are a part of the value of the company since they can be sold in a case of bankruptcy. However, a growth-oriented company does not conventionally own large stocks of tangible assets.

If the company's NPV mainly relies on distant future revenues, it is inadequate to focus on time series for already realised cash flows or profits. Instead, the estimates for the value of the company can be based on the left-hand side of the invisible part in the balance sheet in Figure 2. This part also corresponds to the market capitalisation of a company less book value.

The growth opportunities are often based on the critical mass and quality of intellectual capital. Thus, the intangible assets on the left-hand side of the balance sheet (Figure 2) provide another context for describing the value of intellectual capital as presented in the value platform (Figure 1).

The total equity financing of biopharmaceutical SMEs is estimated to be slightly less than EUR 160 million (Table 2). Most of the companies are owned by persons actively engaged in the business, private venture capital companies, and government institutions providing venture capital, mainly SITRA.[7] Especially in older companies the owners are likely to be other companies. Such companies own over 60% of the shares of biopharmaceutical companies that are more than eight years old.

Table 2 Equity financing by age and size of biopharmaceutical companies

	Persons active in the business	*Other persons*	*Private venture capital company*	*Other financial institution*	*Other company*	*Government institution*	*Other*	*Total equity capital (million euro)*
Total	26%	5%	32%	3%	10%	24%	1%	159
0–4 years	28%	4%	42%	0%	1%	25%	0%	104
5–8 years	22%	8%	14%	8%	18%	26%	4%	42
9–24 years	21%	1%	9%	2%	62%	5%	0%	13
Small	43%	6%	7%	0%	17%	22%	5%	10
Large	24%	5%	33%	3%	10%	24%	1%	149
Turnover under 1.5 million euro	26%	5%	34%	3%	6%	25%	1%	148
Turnover over 1.5 million euro	17%	1%	7%	2%	67%	6%	0%	12
Exports/ turnover under 10%	27%	5%	37%	3%	1%	27%	0%	133
Exports/ turnover over 10%	19%	2%	6%	1%	61%	5%	6%	26
Low R&D intensity	5%	0%	0%	0%	94%	2%	0%	8
High R&D intensity	27%	5%	33%	3%	6%	25%	1%	152

Table 2 Equity financing by age and size of biopharmaceutical companies (continued)

	Persons active in the business	*Other persons*	*Private venture capital company*	*Other financial institution*	*Other company*	*Government institution*	*Other*	*Total equity capital (million euro)*
No patents	25%	8%	0%	0%	47%	13%	7%	3
Patents	26%	5%	32%	3%	10%	24%	1%	156

The companies primarily export their products or services abroad. However, few biopharmaceutical companies have high levels of turnover. Most of the equity financing is focused on firms with turnover below EUR 1.5 million. The majority of companies with higher turnover are owned by Nonfinancial firms.

R&D activities and ownership of intangible assets is of key importance from the point of the companies' revenue expectations. R&D is a critical issue in the pharmaceutical sector owing to the long lags in product development. The time from an innovation spurring development of a drug to the launch of the final product on the market may take 10–15 years. This inevitably means that a start-up firm's R&D activities and intangible assets are of pivotal importance when assessing the firm's expected stream of revenues and consequent present value. For example, Garner, Nam, and Ottoo (2002) evaluate the connection between R&D intensity and the company's market value by using growth options.

Owing to the nature of the biotechnology industry, most of the companies have a relatively high level of R&D activity. On one hand, investors may have stressed the importance of R&D activity by companies as a way of boosting future revenue expectations (Table 2 high R&D intensity). On the other hand, the R&D intensity of the companies may be a signal to investors about future revenue expectations, which makes the company an interesting investment target.

Biotechnology R&D activity spawns patent applications, but also vice versa: companies possessing intangible assets are attractive investment opportunities. For this reason it is not clear whether most of the patent applications and patent ownerships are mainly a result of research financed by equity or whether the company has been an interesting investment candidate because it has had intangible assets such as patents already when the company was financed. Luukkonen and Palmberg (2004) state that holdings of patent applications and patents are a necessary condition for a biotechnology company to obtain equity financing from private venture capital companies.

In this section we have presented the capital structure and sources of equity financing of the Finnish biopharmaceutical companies, broken down by classes describing the nature of the business. In the next section we will seek to form a more systematic overview of the above-described sources of equity financing and intellectual capital using statistical methods.

4 Empirical analysis and results

4.1 Principal component analysis

The analysis will make use of principal component analysis (PCA), which allows us to compress the information contained in the statistical data by using the joint variance of the variables. We constructed new variables based on principal component scores produced by PCA. The principal component scores describe the correlation between selected variables and the mutually independent principal components.[8] In this setting, the correlations estimate the interaction between different categories of intellectual capital. The results of the principal component analysis are presented in the appendix. In principal component analysis the variables are grouped into different principal components that do not present strong mutual correlations, and thus the problem of multi-collinearity is avoided. In the next section presenting the results of the statistical analysis we name three principal components, the eigenvalues of which are greater than 1.5.

The principal component analysis is divided into two steps. First, in Section 4.1 the indicators for intellectual capital within the three separate categories are measured, and interactions between them are presented as a result of principal component analysis. Second, in Section 4.2 the derived principal component scores are classified among different owner groups. The interactions within the three categories of intellectual capital express how separated investor groups have stressed different forms of intellectual capital.

4.2 Measures for value platform

According to the value platform framework the interactions between the three categories of intellectual capital indicate the value creation within the companies. In this study we create principal components that signify interactions between the three categories of intellectual capital. Table 3 presents the principal component solution derived from the value-platform-based variables (other statistics in Appendix 2). The component matrix presents the three principal components with eigenvalues exceeding 1.5. The principal components analysed explain 45% of the variance of the selected variables.

Table 3 Principal component matrix

			Component		
IC category	*Name of variable*	*Variable*	*1*	*2*	*3*
HC	Marketing expertise	Full-time marketing expertise	0.684	–0.287	–0.102
RC	University collaboration	Expenditures for university research per governmental R&D finance	0.629	0.349	0.156
SC	Age	Age of firm	0.575	0.157	–0.222
SC	Innovation intensity	(Patent applications + patents) /labour	0.505	–0.223	–0.008
HC	Industrial expertise	Full-time industrial expertise	0.085	–0.611	–0.183

Table 3 Principal component matrix (continued)

IC category	*Name of variable*	*Variable*	*Component*		
			1	*2*	*3*
RC	Governmental R&D finance	Public R&D support per R&D costs	0.324	0.540	0.299
HC	Managerial experience	CEO's business experience in years	0.392	0.497	0.416
RC	Dependence on principal customer	Principal customer (> 1/3 of sales)	–0.252	0.482	–0.253
SC	R&D intensity	R&D costs per total costs	–0.343	–0.201	0.676
SC	New patent creation intensity	Patent applications/patents	–0.068	–0.394	0.665
RC	Top-5 Auditor	Top-5 Auditor	0.385	–0.459	0.192
HC	PhD intensity	Post-graduated labour per total labour	–0.461	0.177	–0.151
RC	Dependence on principal subcontractor	Principal subcontractor (>1/3 of purchases)	–0.154	0.227	0.462

Note: Extraction method: principal component analysis

The first principal component comprises Marketing expertise, Age, Patent intensity, and University collaboration as variables, thus reflecting Human Capital (HC), Structural Capital (SC), and Relational Capital (RC) of a company (see Figure 3). The second principal component has high loadings with the HC-related variables (Industrial expertise and Managerial experience) and the RC-related variables (Governmental R&D finance, Dependence on principal customer, and Top-5 auditor) (see Figure 5). Principal component number three reflects managerial experience (HC), R&D and innovation intensity (SC), and dependence on principal subcontractor (RC) (see Figure 7).

4.3 Intellectual capital and the owner groups

The derived principal component scores obtained in section 4.1 are classified among the different owner groups. The owners are divided into five groups:

1 individual persons

2 governmental venture capital institutions

3 private venture capital companies

4 other (nonfinancial) firms

5 other owners.

Interactions within the three categories of intellectual capital express how separate investor groups have stressed different forms of intellectual capital.

Principal component scores are, by definition, standardised variables and thus their mean equals zero and their standard deviation equals one. This corresponds to mean and standard deviations of normal distribution irrespective of whether the principal component scores were normally distributed or not.

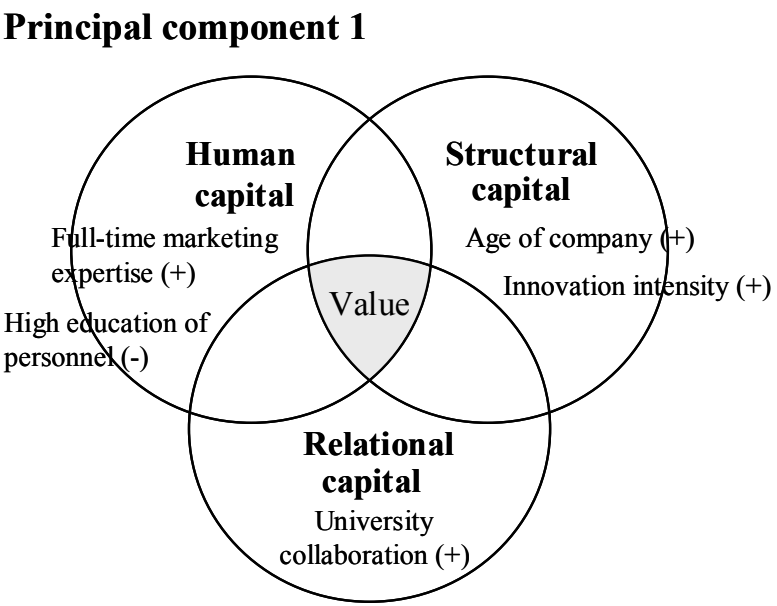
We should find a robust rule on how to divide companies into different groups that indicate low, medium, or high level of some specific forms of intellectual capital. We divided the principal component scores into three subclasses based on a normal distribution. The limits for the subclasses were defined at –0.43 and 0.43, respectively, in order to divide equally the probability density of the normal distribution into three equal subclasses. Employing these criteria resulted in a range of 9–16 companies in each subclass. Using fixed coefficients renders the method applicable to any sample without loosing comparability between sets of samples.

In this study we consider how the various sources of equity financing are related to different categories of intellectual capital. We divide the companies into three groups according to their Intellectual Capital profile: low, medium, and high principal component scores. These scores reflect different combinations of IC.

High values of principal component scores indicate that the variables with high loadings of that specific component receive simultaneously high value, i.e. the category 'high' indicates a well-balanced combination of IC assuming that all significant loadings represent the same (positive) sign. The category 'medium' indicates that no clear and well-balanced IC mix can be identified. The category 'low' indicates that the negative variables dominate in the respective categories.

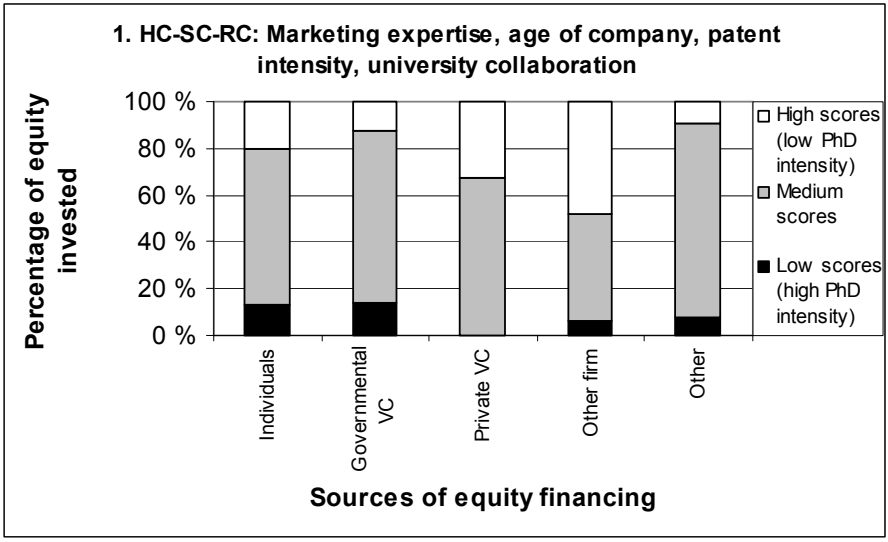
Principal component 1 (Figure 3) is an apparently ideal combination of business knowledge, IPRs, and research collaboration. The mature companies have already created a market for their products, based on their Intellectual Property Rights. R&D is still important, but it has shifted from predominantly in-house capabilities to an intensive collaboration with universities.

Figure 3 The first IC component of the Finnish biopharmaceutical industry in value platform



Other companies have a clear predilection for firms with the aforementioned IC profile; nearly half of the investments are in companies with high values. Private venture capitalists show a similar interest, with more than 30% of their investments in companies with high values, and no investments in companies with low values in the IC mix.

Figure 4 First, HC-SC-RC-related component and sources of equity financing



A similar but less pronounced predilection is found among individuals as well as governmental venture capitalists. However, the investments made by other firms are divided equally between companies reflecting high, and medium or low values, respectively. At first this seems surprising as e.g. acquisitions are usually made after a thorough due diligence with only the best companies chosen and assimilated. However, companies owned by other firms can be driven on functions in a very specialised part of the parent firm's value chain. Consequently, the IPR portfolio and marketing functions can be transferred to other parts of the group as corporate functions.

Principal component 2 (Figure 5) contains high loading variables showing opposite signs; additionally the Structural Capital category is not represented at all. This hampers an interpretation within the value platform framework.

Figure 5 The second IC component of the Finnish biopharmaceutical industry in value platform

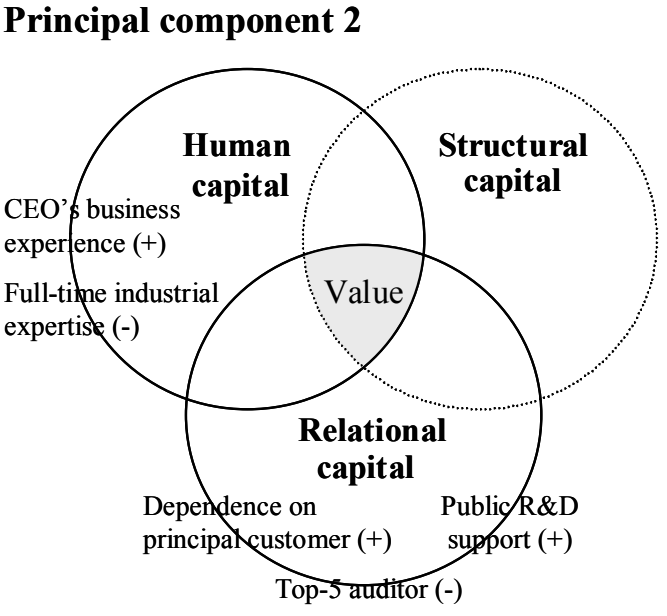
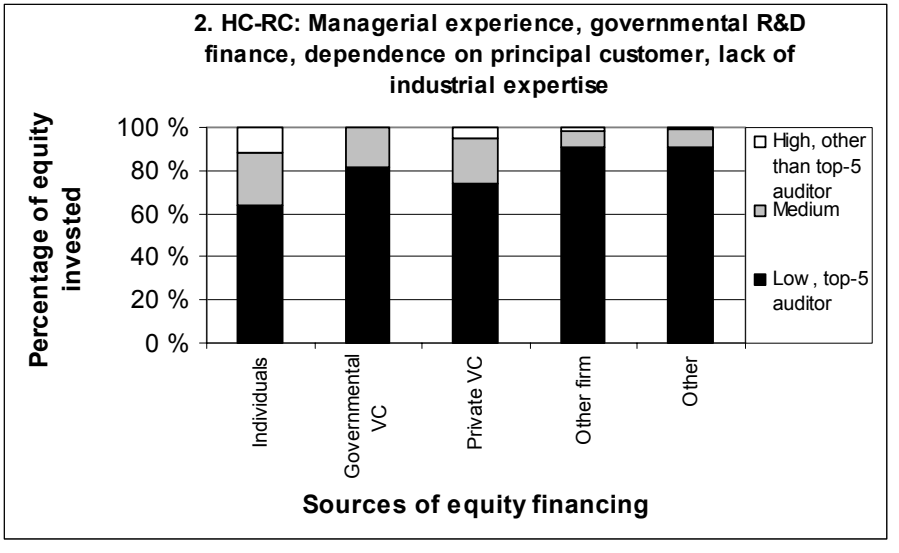


Figure 6 The second, HC-RC-related component and sources of equity financing



All owner groups seem to prefer industrial expertise and a top-5 auditor. Forty-one percent of the companies disclose that they employ at least one full-time industrial expert. Seventy-one percent of the companies use top-5 auditors; in monetary terms the top-5 auditors are utilised in companies representing as much as 95% of all inflow of equity financing. This indicates that major investors require highly credible monitoring of the managers

This indicates that a highly credible monitoring of the managers is a prerequisite for major investments.

The third principal component includes two critical variables from the structural capital: R&D intensity and new patent creation intensity (Figure 7). Their mutual correlation is 0.50 ($p = 0.001$), and they co-variate irrespective of the empirical model. Thus we conclude that intensive R&D creates a stock of patent applications. This is, together with managerial experience and a preferred subcontractor, regarded as a viable mix of IC. However, other firms have invested equal amounts also in companies with an opposite mix. This illustrates again the dichotomy of investments made by other firms.

Figure 7 The third IC component of the Finnish biopharmaceutical industry in value platform

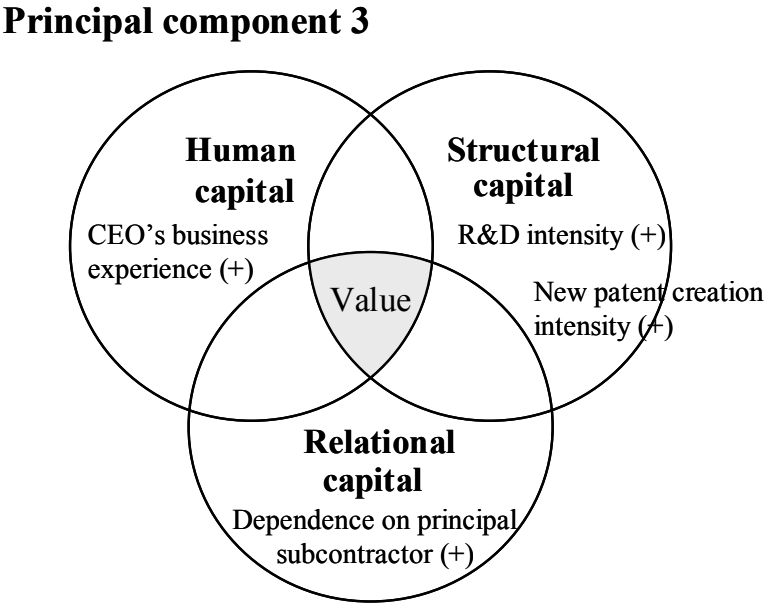
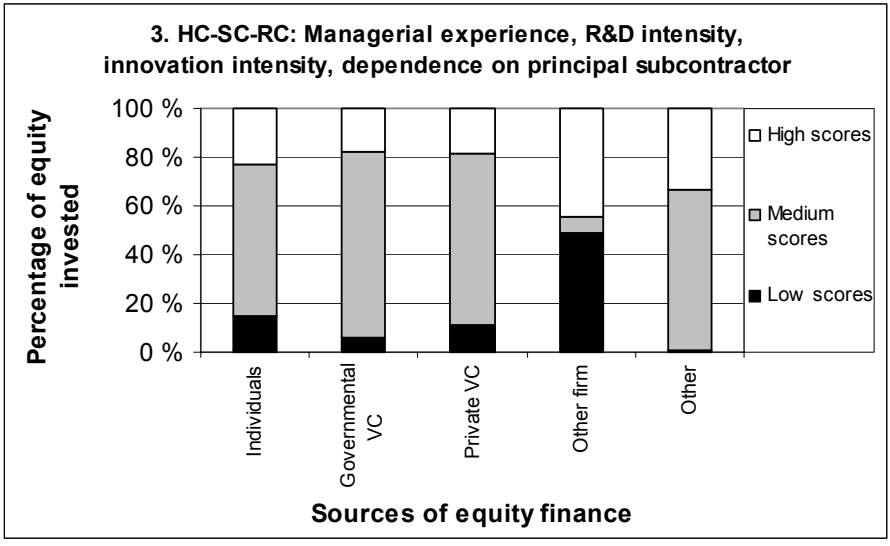


Figure 8 The third, HC-SC-RC –related component and sources of equity



The IC mix of principal component three seems not to have influenced the investment decisions of other investor groups than 'other firm.' This could be a result of each investor stressing their specific profile of IC, or the investors applying a different palette of IC components in each investment decision depending on the business logic of the target company. As an example, a company developing new drugs must be based on patent protection, but a producer of generic drugs or research services is not necessarily dependent on an own patent portfolio.

5 Conclusion

The growth opportunities of small and medium-sized biopharmaceutical companies often lie in the distant future, and thus they are in need of external finance to reach the market. The valuation of this kind of a knowledge-intensive company can be expected to be based not only on historic earnings data, but also on intellectual capital indicating the future earning prospects of the company.

We processed survey data in three steps in order to provide answers to the aims of the study. First, the sources of equity financing were identified, yielding five distinct groups of owners. Second, we formed several indicators for subcategories of IC and constructed intellectual capital components based on the value platform framework, which combines the three categories of intellectual capital. Third, we identified how IC components are related to the equity financing of the distinct groups of owners.

The financing received from the company's investors is usually equity financing and to a lesser extent capital loans, judicially on equity terms. Conventional loan financing is not a main form of financing in the biopharmaceutical sector. An exit is critical particularly for an early stage investor. In the current situation prevailing in the financial markets, obtaining a listing on the stock exchange does not seem a realistic option. The

licensing and royalty payments as well as mergers and acquisitions are the most common ways of securing consecutive rounds of financing for commercialisation projects. This study setup was not designed to identify dynamic aspects in the investment patterns. However, principal component analysis revealed combinations of variables that were able to distinguish patterns of equity financing preferences.

According to the value platform theory the interaction of the three categories of IC predicts the value creation ability of the company. This is emphasised in the biopharmaceutical sector as the value creation is typically expected to be fully realised far in the future, thus closely arguing the use of the value platform approach. We were able to identify three principal components which included all three categories of intellectual capital. The principal component scores for each factor were derived, enabling a creation of IC profiles for the companies.

The IC profiles derived were able to diversify between investment preferences of different owner groups. *Other firms* possess equity in biopharmaceutical companies with two different profiles of intellectual capital. This probably reflects two different subgroups of companies, corresponding to different strategic functions designated to the company by the owner firm. *Venture capital companies* represented the largest investor group. They seem to prefer a well-balanced combination of intellectual capital, even more than other owner groups. *Individual owners, Governmental venture capital institutions*, and *Other investors* showed among themselves a rather similar pattern of investment preferences. The role of individual owners and governmental venture capital institutions is emphasised in the early stages of a biopharmaceutical company's life cycle. These investor groups have directed funds to companies whose corresponding intellectual capital profiles indicate that all IC categories are not fully balanced.

In this paper we have presented a new way of measuring intellectual capital based on the value platform framework. The development of this kind of a theoretically well-grounded tool is particularly essential in knowledge-intensive and science-based sectors.

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Notes

1 ETLA is an abbreviation for The Research Institute of the Finnish Economy.

2 Below we use the term SMEs to denote small and medium-sized enterprises. A company is called small or medium-sized if two of the following three conditions are met: the company has a maximum of 250 employees, its turnover does not exceed EUR 40 million and its total assets are less than EUR 27 million.

3 In this paper we will use names for the three categories according to MERITUM Project (2002) Guidelines for Managing and Reporting on Intangibles (Intellectual Capital Report). Fundación Airtel Móvil, Madrid.

4 Nonaka and Takeuchi (1995) define their seminal model in which they interpret how the tacit knowledge is converted to explicit knowledge and back to the tacit knowledge of other individuals and groups. In the present study we do not focus on the so-called SECI model but instead we focus on measuring the intellectual capital of the Finnish biopharmaceutical SMEs and how the revealed intellectual capital is related to different sources of equity financing.

5 Tekes stands for The National Technology Agency of Finland.

6 For an overview of theories on companies' capital structures see e.g. (Myers, 1984; 2001).

7 Sitra denotes the Finnish National Fund for Research and Development.

8 E.g. Sharma provides a detailed technical presentation of principal component analysis. Sharma, S. (1996) *Applied Multivariate Techniques*, New York: John Wiley & Sons, Inc.

Appendix 1

Table A1 Comparison of Finnish biopharmaceutical SMEs and SMEs as a whole (Hermans 2003)

		Bio-pharmaceutical SMEs	*Total SMEs*
		%	%
Number of personnel	< 5	33%	44%
	5–20	38%	41%
	> 20	29%	15%
Turnover, million euro	< 0.2	45%	15%
	0.2–1.5	40%	56%
	1.6–8.0	12%	24%
	> 8	2%	5%
Exports/turnover	0%	43%	70%
	0–1%	2%	22%
	2–5%	7%	4%
	6–10%	0%	2%
	> 10%	45%	3%
	Unknown	2%	0%
Age of company, years	0–2	14%	5%
	3–4	21%	9%
	5–24	64%	70%
	> 24	0%	16%
R&D expenditures/total costs (total SMEs = R&D expenditures / turnover)	0%	5%	53%
	0–1%	2%	23%
	2–5%	5%	13%
	6–10%	7%	3%
	> 10%	79%	6%
	Unknown	2%	0%
Company has patents or patent applications	Yes	74%	6%
	No	26%	94%
Company's expected turnover growth over next 5 years (total SMEs = next 3 years	< 0%	0%	1%
	0–1%	2%	31%
	2–5%	0%	20%

Table A1 Comparison of Finnish biopharmaceutical SMEs and SMEs as a whole (Hermans 2003) (continued)

		Bio-pharmaceutical SMEs	*Total SMEs*
		%	%
	6–10%	10%	23%
	> 10%	86%	21%
	Unknown	2%	5%
Total observations in sample		42	754

Appendix 2

Table A2 Descriptive statistics of the IC indicators

Descriptive statistics	*N*	*Minimum*	*Maximum*	*Mean*	*Std. Deviation*
Post-graduated labour per total labour	41	0	1	0.354	0.313
Manager's business experience in years	41	1	40	10.366	8.387
Full-time industrial expertise	41	0	1	0.415	0.499
Full-time marketing expertise	41	0	1	0.341	0.480
R&D costs per total costs	41	0	1	0.503	0.357
Innovation intensity (patent applications + patents/labour)	41	0	21.42857	2.097	4.497
New patent creation intensity (patent applications/patents)	41	0	7.75	1.015	1.614
Age of firm	41	0	21	6.756	4.504
Share of public R&D support used in university research	39	0	1	0.243	0.343
Public R&D support per R&D costs	38	0	1	0.272	0.292
Top 5 Auditor	41	0	1	0.707	0.461
Principal customer (> 1/3)	41	0	1	0.439	0.502
Principal subcontractor (> 1/3 out of purchases)	41	0	1	0.195	0.401
Valid N (listwise)	37				

Table A3 Total variance explained by principal components

Component	*Initial eigenvalues*			*Extraction sums of squared loadings*		
	Total	*% of variance*	*Cumulative %*	*Total*	*% of variance*	*Cumulative%*
1	2.287	17.590	17.590	2.287	17.590	17.590
2	1.912	14.709	32.299	1.912	14.709	32.299
3	1.617	12.440	44.739	1.617	12.440	44.739
4	1.368	10.522	55.261			
5	1.231	9.467	64.728			

Table A3 Total variance explained by principal components (continued)

Component	*Initial eigenvalues*			*Extraction sums of squared loadings*		
	Total	*% of variance*	*Cumulative %*	*Total*	*% of variance*	*Cumulative%*
6	0.996	7.664	72.392			
7	0.951	7.318	79.710			
8	0.750	5.771	85.480			
9	0.621	4.776	90.257			
10	0.438	3.373	93.630			
11	0.360	2.771	96.401			
12	0.284	2.186	98.587			
13	0.184	1.413	100			

Note: Extraction method: principal component analysis

Appendix 5. Funding Intellectual-Capital-Abundant Technology Development

Tahvanainen, A.-J. – Hermans, R. (2005). Funding Intellectual-Capital-Abundant Technology Development: Empirical Evidence from the Finnish Biotechnology Business. *Knowledge Management Research & Practice*, vol. 3, no. 2, 69-86.

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Funding intellectual-capital-abundant technology development: empirical evidence from the Finnish biotechnology business

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Abstract
This study takes an interdisciplinary approach to answering the questions of whether and how the intellectual capital (IC) of a company is related to its financial structure. To this end, we consecutively apply factor and regression analyses on a sample of 65 small and medium-sized Finnish biotechnology companies. Based on the results, we find that firms with a well-balanced IC base finance their operations to a larger extent with retained earnings and debt while companies with less well-balanced IC bases revert to other sources of financing, for example, external equity. Utilizing the conventional pecking order theory as a theoretical backdrop on one hand and recent results from its empirical research on the other, we present two alternative rationales behind deviating capital structure choices made by companies with dissimilar IC bases.
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Keywords: capital structure; financial pecking order; intellectual capital

Introduction

Background

Conforming to the laws of the market mechanism, a company's ability to raise financing is directly linked to its value as perceived by investors. For the assessment of companies' market values, in turn, investors usually consider key indicators like, for example, present market shares, product portfolios, business expertise, turnover figures, and profitability indices, as well as future forecasts thereof. Based on the indicators, it is possible to compute net present values (NPV), pay-off periods, and other indicators that describe the productivity of investments. These indicators serve as the basis for investment decisions.

However, the valuation of companies in knowledge-intensive industries, like biotechnology, can be executed only with high risks based upon such indicators. Companies in knowledge-intensive industries are frequently unable to provide reliable indicators and show certain distinguishing characteristics that make it difficult to assess their value. In Finland, they cannot even be assessed relying on their historical development due to the infant nature of the entire industry. In these industries, the book value on the balance sheet conveys only limited information on the true value of companies as the capitalization of R&D expenditures on the balance sheet is optional and thus, two otherwise identical firms may appear different if just the balance sheet information is consulted. Even more importantly, intellectual capital (IC), the most critical engine of value creation

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according to the knowledge management literature, is not captured in the balance sheet at all (Edvinsson & Malone, 1997; Sveiby, 1997; Lev, 2001).

In 2002, many Finnish biotechnology companies were still in an infant stage of commercialization. Over 40% of companies founded after 1991 showed negative profits and approximately 60% showed a personnel count of 10 or less. Only 49% employed a full-time marketing expert (Hermans & Luukkonen, 2002). On the other hand, the share of employees with a scientific education was high. 60% of firms employed personnel that also held a university position. Moreover, with high R&D intensities the business risk is pronounced, making a reliable assessment of company value even more difficult as the probability of success in this early stage of operations is still relatively uncertain. This translates into difficulties obtain to financing as observed by Hermans & Luukkonen (2002), especially concerning companies with a history rooted in academia (Tahvanainen, 2004).

Nevertheless, returns in case of success can more than offset the risks. In global markets, revenues created by pharmaceutical products, for example, are massive. The question is how to evaluate these knowledge-intensive businesses without conventional indicators. One answer has been proposed by the knowledge management literature, whereby the intellectual capital base of a company is the primary source of value and the generator of future sales (Edvinsson & Malone, 1997; Sveiby, 1997), and thus might serve as a base for value assessment. The hypothesis is suitable for knowledge-intensive industries since it measures intangible assets that should already be in place even in young and small companies that have not necessarily entered the markets yet. Supportive of the theory, Hermans & Kauranen (2005) are able to estimate 70% of the anticipated future sales of Finnish biotechnology SMEs based on their respective intellectual capital bases.

Assuming that the intellectual capital base is a good proxy for the ability to generate value and provide investors with information necessary to make reasonable investment decisions, it should implicitly have an effect on the ability of a company to obtain financing. Prior to this study, Catasús & Gröjer (2003) have examined this effect on the availability of debt financing. We expand the examination to comprise the whole capital structure including retained earnings, capital loans (capital loans are loans that satisfy the regulations enacted in the Finnish Companies Act. The act states that capital loans must be included in the shareholders' equity in the financial statement) and external equity.

We also contribute to the discussion by applying conventional capital structure theory to justify capital structure choices made actively by sample firms.

Aims and methods

This study analyzes the questions whether and how the IC of a company is related to its financial capital structure and its use of distinctive sources of financing in a cross-section of 65 small- and medium-sized Finnish biotechnology companies. As a theoretical backdrop, we utilize both the recent knowledge management literature and the capital structure literature in the construction of our empirical model.

In terms of methodology, we apply a two-staged approach. In the first stage, the intellectual capital of companies is measured leaning on the value platform model introduced by Edvinsson & Malone (1997). The presence of different configurations of the three IC components (human capital, structural capital, and relational capital) in companies is captured by feeding IC indicators into a factor analysis. The analysis uses the indicators to form factors and factor scores representative of the IC configurations in the sample companies. In the second stage of the analysis, the IC factor scores obtained in stage one serve as independent variables in a linear regression analysis that estimates the capital structure ratios of sample companies that are constructed based on the capital structure literature, especially Myers' (1984) financial pecking order hypothesis.

The paper proceeds as follows. In the subsequent section, we elaborate on the theoretical background, namely the theories on financial capital structure and intellectual capital. Following that, we present the underlying data. Thereafter, the two-staged analysis is elaborated on in detail, followed by the presentation of results. In the discussion of findings, we contrast our results to other recent empirical literature and discuss alternative modeling approaches. The final section closes the paper with conclusions.

Theoretical background

Capital structure literature

The capital structure literature is rather broad, encompassing numerous theories on the rationale behind capital structure choices. In this study, we utilize only Myers & Majluf (1984) and Myers (1984). Comprehensive reviews on the literature as a whole are presented by Harris & Raviv (1991), as well as Klein *et al.*, (2002).

Myers & Majluf (1984) argue that the information asymmetry between insiders of a company and potential investors results in some cases in a decrease of equity value when equity is issued and a rejection of positive NPV investments in others. The chain of argumentation leading to these hypotheses goes as follows.

For simplicity, firms are divided into high value (H) and low value (L) companies. In our case, type H firms are endued with a well-balanced IC base, whereas type L firms display an IC base lacking at least one of the three IC components. Reality is not as simple, of course, but if the terms 'high' and 'low' describe the relative values of companies under comparison, not absolute values, this simplified setting can be transferred to describe any two firms. For investors, it is not possible to determine whether the firm they are about to invest in is type H or L since asset value and revenue streams, and in our

case also intangible assets, are assumed to be unobservable before the equity issue. Thus, we have the case of information asymmetry addressed above. For the argumentation to hold, Myers & Majluf (1984) assume that the management maximizes the value of existing shareholders and that investors are rational.

Consider a project that needs outside financing. The outside financing comes in the form of an equity issue and finances 100% of the project. In the moment of the issue, investors cannot observe whether the issuing firm is type H or L due to the information asymmetry. All they know is that if they valued the equity of the issuing company according to the true value of an H type firm and the firm turned out to be type L after the issue, current stakeholders of the L type would gain supernormal pay-offs and new investors would pay too much for their claims due to the overpricing. It is not in the interest of the managers of an L type firm to identify themselves as such, because they maximize the wealth of their current shareholders. Pretending to be type H just might work out, and the equity is overpriced, earning the current shareholders supernormal wealth gains in the amount of the overpriced margin. Anticipating this behavior and being unable to verify the true value of the firm, investors accordingly adjust the price offer for the equity downwards. The result for the L type firm is that its equity is priced fairly. Current shareholders let go of a fraction of their claims equal to the fraction of the investment of total firm value including the added NPV of the project, and gain the net present value of the project.

For an H type firm the situation looks worse. Since the firm cannot credibly verify its true type, the equity to be issued is underpriced by the investors. If the resulting wealth loss incurred to the current shareholders of the firm does not exceed the value created by the investment (i.e. the NPV of the project), the project will still be accepted if and only if the project cannot be financed by any other means. But if undercutting the real equity price is severe enough, that is, the difference of the true value of the H type firm and the value predicted by the investors is sufficiently large, the loss incurred is greater than the value created by the project, and current shareholders experience a net wealth decrease. In this case, the project will be rejected although it has a positive net present value and no equity is issued.

The argumentation implies that, in equilibrium, type H firms never issue equity, and if they do, only as a last resort. L type firms, on the other hand, are always eager to issue equity since they have nothing to lose. Thus, the issue of equity is a signal that the firm is type L. In case of an equity issue announcement, investors therefore tend to lower their assumption of the firm value, no matter what type the firm is, leading to a fall in the value of existing shares.

Myers (1984) names the implications of the argumentation the 'pecking order theory'. He argues that investments of a firm are financed according to the following pecking order. First, a firm in need of financing draws on internal sources. Since the information asymmetry does not appear among insiders, there is no wealth destroying aspect to it. Company shares will not be downgraded. Also, internal financing does not involve any issue costs and is therefore preferred to any kind of outside financing, even if terms would otherwise resemble those of internal funding. Second, only if internally generated cash flows are insufficient to fund all positive NPV projects do managers consider issuing securities of any kind. This can happen, for example, if in times of fluctuating cash flows a sticky dividend policy inhibits the flexible use of cash (i.e. canceling dividend payments and redirecting funds to investments) or cash is simply not generated, as in the case of many biotechnology companies. In such cases, firms always issue debt before equity, because its value is independent of asymmetric information. The single debt security is a fixed claim worth the same no matter whether the firm is of type L or H, assuming that the target of investment and the related risk is known to investors. Thus, debt is priced fairly and is cheaper than equity. Outside equity is at the bottom of the pecking order since its issue incurs the depreciation of firm value on top of the usual issue costs, which are already more expensive for equity than debt.

Myers' (1984) theory has implications on the study at hand. If Hussi (2004) is right and intangible assets are indeed not taken into account by investors, as argued below, the information asymmetry concerning firm value between the companies and financial markets persists, and we should obtain empirical evidence from the data that is in line with the pecking order theory.

Knowledge management literature

We base the measurement of intellectual capital in the sample companies on the value platform model initially introduced in Edvinsson & Malone (1997). The model is presented graphically in Figure 1. The names for the three components of IC, namely human, structural, and relational capital, have been modified to match the definitions proposed by the MERITUM project (2002) (see also Edvinsson & Malone, 1997; Sveiby, 1997). Sveiby (1997) labels the components 'individual competence', 'internal structures', and 'external structures' respectively. Edvinsson & Malone (1997), in turn, talk about 'customer capital' instead of external structures disregarding thereby relationships to all other stakeholders like suppliers, competitors, academia, and so forth that are critical for advancing research towards the market place, as successful R&D activities are often conducted within networks of cooperation (see, e.g., Nilsson, 2001; Hermans & Luukkonen, 2002).

According to the value platform model, value is created in a company when all three components of IC, the generative intangible assets (Hussi, 2004), are managed in a way that they support each other. This is the very purpose of knowledge management. While human capital encompasses the knowledge, experiences, skills,

and competencies of the personnel, structural capital comprises physical and conceptual structures present in the company that facilitate the support, enhancement, protection, intra-firm distribution, and documentation of human capital residing in the company. Relational capital can be understood as a network of virtual and physical relationships and connections among the critical stakeholders of a company. Through this network, the company is able to leverage intra-organizational achievements, be it products, intellectual property rights, services, results of research, communication, or people to the periphery of the company. According to the model, all three components are critical success factors in the sense that in the absence of any single component only modest value can be created. The aim of the above-mentioned factor analysis will be to identify and separate companies enduing all three components of IC from companies with incomplete IC bases.

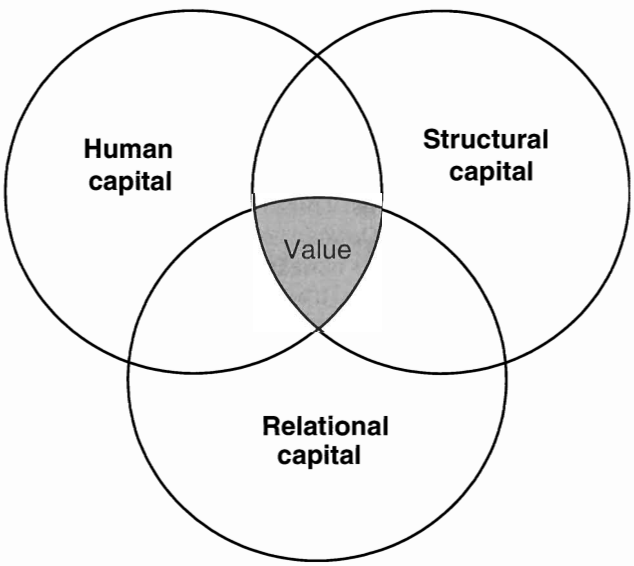

Figure 1 Value platform model.

According to Hussi (2004), the interaction of the generative intangible assets creates value by turning knowledge into commercially exploitable intangible assets. Such assets can be, for example, cost efficient production processes, intellectual property rights, functioning customer relations, expanding markets, and so forth. These are assets that a company can immediately benefit from financially. Figure 2 shows the comprehensive framework that clarifies the role of intangible assets, comprising both generative and commercially exploitable intangible assets, in the generation of long-run productivity of capital. Since we are not primarily interested in the whole picture but rather in the factors, based on which the financial markets evaluate potential target companies, we have modified Hussi's (2004) model to include a pointer depicting this aspect (black arrow). Otherwise Figure 2 matches the original in Hussi (2004).

Revisiting Hussi's (2004) framework shortly, there are three factors that affect the long-run productivity of capital employed in a company. These are intangible assets, tangible assets, and the expectations of the market. All three factors are influenced and coordinated by appropriate leadership on the part of the company.

What the framework fails to address is the direct interaction between intangible assets and market expectations, more specifically the financial markets. It assumes that investors do not take intangible assets into

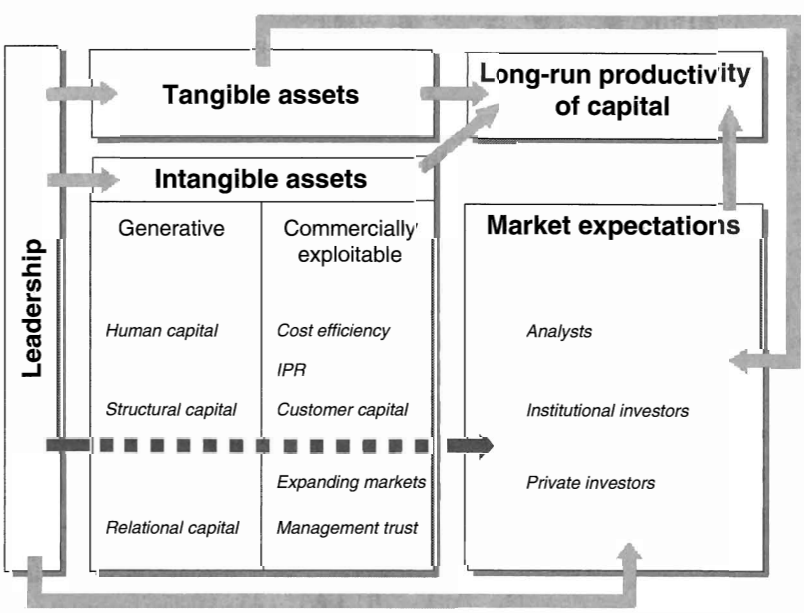

Figure 2 Factors of long-run productivity of capital – modified from Hussi (2004).

account when evaluating a company. As Hussi (2004) states, 'in reality, the financial markets turn out to base their estimates on relatively limited information, as they tend to use mainly information on leadership, management, and tangible assets and even in the best cases scant information on intangible assets.' Thus, Hussi (2004) does not interconnect intangible assets with market expectations.

In the present study, we challenge this view. We claim that intangible assets are measurable using existing 'knowledge management metrics' as reviewed by, for example, Liebowitz & Suen (2000). Exemplary empirical application of such metrics has been performed by Hermans & Kauranen (2005), Hermans & Kulvik (2004), and Hermans (2004). Another claim is that investors use these metrics in the evaluation process of a company. Additionally we propose that, instead of directly evaluating the leadership of a company, investors also use the metrics to assess the quality of leadership indirectly as it expresses itself endogenously in the degree of balance of the IC base. This is intuitive, since good leadership within the value platform framework aims at a well-balanced IC base as a focal engine for value creation. In the case of knowledge-intensive industries, the intangible asset-based valuation of companies would be especially well-founded, since in these industries intangible assets are of far greater value than any other type of asset. Thus, disregarding intangible assets would render the valuation of a knowledge-intensive company futile.

In order to be able to test our claims, we need a pecking order framework that deals explicitly with the kind of information asymmetry that arises between the firm and the financial markets due to the alleged unwillingness of investors to regard intangible assets. Companies with a well-balanced IC base should shun external financing, especially external equity, and utilize internally generated cash flows more heavily than other types of firms. It should be pointed out that the pecking order theory claims that the capital structure of a particular firm is determined by the firm itself choosing the most inexpensive source of financing at a given point in time. It does not address situations in which financing is rationed by the financial market and certain financing sources are simply not available. Leaning on in-depth experience from the Finnish biotechnology sector, we take this matter into consideration when discussing the results in the concluding part of the study.

Sample and data

The analysis at hand is based on cross-sectional private survey data comprising 64 small and medium-sized Finnish biotechnology companies (biotechnology SMEs) at the end of 2001. The data were collected via phone interviews at the beginning of the year 2002. SMEs in this paper are defined according to official definitions of the EU excluding firms that employ more than 250 people and match additionally at least one of the following criteria: (i) Annual turnover >40 million euro, (ii) balance sheet total >27 million euro. Data concerning balance sheet items has been supplemented and checked with data from the National Board of Patents and Registration of Finland (PRH). The original survey encompasses 84 biotechnology companies, the majority of the 120 companies that were operational in 2001 in the Finnish biotechnology sector. Out of these 84 companies, 72 were small and medium sized. The final sample of 64 companies used here is somewhat smaller due to missing values in some individual cases.

The companies in the sample are independent businesses, partnerships, or subsidiaries of bigger corporations. In the two latter cases, the businesses must be independently responsible business units in order to be included in the sample. If the criteria are not fulfilled, the data is collected from the parent company. No companies 25 years or older met the criteria for inclusion. It should be pointed out that the majority of firms excluded for their large size belonged to this age category and the remaining 'old' firms could not be included due to the lack of coherent data. Therefore, the final sample consists of SMEs that are younger than 25 years. There are no severe outliers in terms of data on equity, capital loans, or debt.

The data contains information on company backgrounds, the start-up phase of companies, products, markets, and customers, as well as R&D activities and financing. The information on financial aspects includes the affirmed financial statements of 2001.

Methods and selection of variables

The empirical part of this study consists of a two-stage analysis that aims at relating intellectual capital residing within a firm to its capital structure.

In the first stage, we apply a factor analysis that serves three purposes. Firstly, it identifies different configurations of interaction between the variables representing the three components of IC by breaking down the data into non-correlated factors, with each of them representing a certain configuration. We are especially interested in configurations that display interaction between all three components of intellectual capital, but also need configurations of only two or just a single component in the second stage of the analysis as benchmarks. Secondly, by using the factor analysis technique in the first stage, we avoid potential problems in the second stage of the analysis that might be evoked by correlation among the variables used, since the factors are not correlated. Finally, we need the factors, and the factor scores thereof, as input for the second stage of the analysis.

In the second stage, we use a linear regression model to estimate whether and how the capital structures of companies with differing IC configurations deviate from one another. According to their respective IC configuration, companies receive factor scores in the first stage of the analysis that are then used to estimate their capital structure in the second stage. Based on the results of the second stage, we can draw implications on the

relationship between IC and the pecking order hypotheses of Myers (1984).

Factor analysis and independent variables

As already stated above, the purpose of the factor analysis is to form factors that represent different configurations of IC components. Loosely speaking, the generalized least-squares (GLS) factor analysis identifies correlating variables from the set of IC indicators that are input and groups them together as factors that are not correlated with each other. In the present study, we use the VARIMAX rotation method to ensure that the resulting factors are clearly distinguished from one another for higher informational quality. As a result we obtained five factors, each representing a certain configuration of IC. They are presented in Table A2 in Appendix A.

Concerning the construction and choice of variables that measure the quality and quantity of individual IC categories, we lean on the concept of intangible assets displayed in Figure 2 above. Therein intangible assets are subdivided into generative intangible assets and commercially exploitable intangible assets. The separate examination of generative intangible assets and commercially exploitable intangible assets allows us to determine the individual effects that the two categories have on the capital structure of a company.

Commercially exploitable intangible assets

We use three variables for the approximation of commercially exploitable intangible assets (CEIA). Instead of measuring exploitable intangible assets directly, we measure the outcomes of successfully commercialized intangible assets. The first variable is a straightforward turnover indicator measuring the turnover of sample companies in euros per year. It can be argued that turnover quantifies the level to which intangible assets are actually exploited. The second variable measuring commercially exploitable intangible assets is a dummy indicating whether companies have brought an innovation to market in the past three periods. The third indicator is a ratio indicating turnover per employee that measures the companies' efficiency in creating returns as related to labor input. Descriptive statistics for all three variables are presented in Table 1.

Generative intangible assets

For the identification of variables that approximate generative intangible assets appropriately, we rely mainly on the discourses of Sveiby (1997). According to Sveiby, the variables can be broken down into three separate variable classes with each representing a different aspect of generative intangible assets and business as a whole. These classes can be named according to the aspects they are representing, namely, (i) growth and renewal, (ii) efficiency, and (iii) stability.

It can be argued that variables from all three classes are included in the analysis. Nevertheless, it should be pointed out that the class measuring aspects of stability, in particular, is underrepresented. This is because many companies in the sample are still rather young and in the pre-market phase of operations, where stability aspects are not of a central concern. The utmost priority of these companies is to invest heavily in R&D that, in time, will result in a commercially exploitable product or service that will recoup prior investments. R&D investments are very risky in nature and incompatible with the notion of stability by definition. On the other hand, and for the very same reason, the variable class representing aspects of growth and renewal is strongly represented.

In the following, we present all variables that are included in the factor analysis. In accordance with the value platform model of intellectual capital, we have divided the generative intangible assets and the variables approximating them into the three components, namely, human, structural, and relational capital. Each component is treated separately. In conjunction with the presentation of variables in each category, we also briefly discuss which of the variable classes (growth and renewal, efficiency, stability) the particular variables belong to.

Human capital

Four distinct variables are chosen to approximate human capital (HC). These variables comprise (i) the total number of personnel, (ii) the share of personnel holding a doctoral degree, (iii) the experience of the chief executive officer measured in years, and (iv) a dummy indicating whether the companies are endued with full-time in-house marketing expertise. Hermans & Kulvik (2004) use similar variables for the purposes of measuring human capital.

As knowledge in its natural, uncodified, and tacit form resides within individuals, we utilize the total number of personnel to capture and quantify the total mass of knowledge inherent in the companies. As the biotechnology industry is knowledge-intensive in character and depends on human capital as the engine of innovation, we assume that a critical mass of complementary and cohesive human capital is essential for super-normal

Table 1 Descriptive statistics for variables measuring CEIA

Variable	N	*Min*	*Max*	*Mean*	*Std. deviation*
Turnover (ln)	69	0.00	18.90	11.04	4.596
Innovation on markets	72	0.00	1.00	0.65	0.479
Turnover per employee (million euro)	69	0.00	5.38	0.13	0.650

performance, or taken to the extremes, for survival. In order to avoid problems that result from a skewed distribution of the variable, we transform the variable into the logarithmic form with the natural base.

The share of personnel holding a doctoral degree is obtained by simply dividing the number of personnel with a doctor's degree by the total number of personnel. As opposed to the latter variable that measured the quantity of human capital, this indicator expresses its quality. We assume that through the educational training and the related practical experience, doctors possess the ability to apply knowledge in a more structured and efficient way. Additionally, we assume that doctors have, thereby, assimilated more knowledge than personnel without a doctoral degree.

In contrast to the two latter indicators, which measure human capital related to scientific knowledge, the two remaining indicators quantify knowledge that is related to organizing and managing a company as a business. The CEO's business experience is measured in logarithmically transformed years. The variable indicating the existence of marketing expertise in-house is a dummy variable and quantifies roughly the knowledge required for the promotion of products and services on markets.

While the number of employees over time directly expresses the growth of a company and can therefore be argued to belong to the variable class of 'growth and renewal', at least the latter two variables can be classified to indicate stability.

Structural capital

The structural capital (SC) of a company includes activities, schemes, policies, and programs, as well as systems, regulations, guides, rights, and facilities that support, enhance, protect, distribute, and document the human capital residing in that company. In more concrete terms, this includes the organization of activities like R&D, the protection of R&D investments with immaterial property rights, company policies on diverse aspects like secrecy and competing activities, information systems and guidelines concerning the standards of conduct in the laboratory, as well as bonus and educational programs.

In the IC literature, one encounters numerous alternatives for measuring structural capital. According to the ICM Group study (1998) SC can be proxied by, for example, administrative expenses, computers per employee, corporate quality performance, and investments in IT. Roos *et al.*, (1998) suggest measures like training expenses per employee, renewal expenses, and new patents filed. Sveiby (1997) lays emphasis on information technology inputs. In this study we utilize four different indicators to proxy structural capital that are more in line with Deeds' (2001) notion, stressing the importance of research and development-related activities for the maximization of a company's innovation potential and, thus, its value creation ability.

The indicators used here are (i) R&D costs per employee, (ii) number of patents per employee, (iii) the share of patent applications of the sum of applications and existing patents, as well as (iv) the age of the company. As opposed to Sveiby's (1997) more static IT-oriented variables that can be argued to belong to the class 'stability', the included variables clearly represent the variable class 'growth and renewal' and express the companies' ways of organizing their research and development activities that aim at maximizing their respective innovation potential.

The variable indicating R&D costs per employee is obtained by dividing the number of personnel by total research and development costs. It expresses the intensity with which a company aspires to transform the human capital residing in its personnel into commercially exploitable assets by providing incentives, facilities, equipment, and other resources that translate into R&D costs. This variable belongs to the class 'growth and renewal'.

In this study, the number of patents per employee is a measure of structural capital. It is not conceived to be a measure of commercially exploitable intangible assets as in, for example, Ahonen (2000). Surely, Ahonen's argumentation, that patents *per se* can be sold or licensed and generate revenues thereby, holds and speaks in favor of his categorization of the variable. Nevertheless, it should be pointed out that the number of patents conveys no information on the quality of these and, thereby, on the extent to which they actually are commercially exploitable. In other words, the sheer presence of patents does not imply their importance to the companies' value creation. In this study, we interpret patents as a structural device for the codification of tacit knowledge, that is human capital, and the investments therein. From this perspective, it is justifiable to see patents as structural capital. Another argument in favor of this interpretation relates to the fact that patents are the tangible output of human capital that is owned by the company as opposed to human capital itself that is the property of each individual employee. By patenting, the company secures its proprietary rights to the products of human capital that could otherwise spillover outside the company with any employee leaving the organization.

The variable indicating the share of patent applications of the sum of applications and existing patents describes the state and nature of the company. A company that displays very few new applications in comparison to its existing patent portfolio is more established and static in nature and exploits already existing assets. It has its roots in the past. A company with a high share of patent applications, on the other hand, is more dynamic, strives to renew itself and expects to create value in future. This variable belongs to the class 'growth and renewal'.

The age of a company expresses the stability of operations and the ability to create value steadily. It also proxies the amount of learning that has taken place within the company and become a part of the company

structure. Usually, such learning is eminent in, for example, established unwritten codes of conduct that have proven to be efficient. Since such codes and ways of doing things are not codified in the data, we revert to age as an approximation.

Relational capital

Relational capital (RC), in contemporary literature also often referred to as customer capital (Edvinsson & Malone, 1997; Stewart, 1997), can be measured in many ways. Indicators of relational capital include, according to the ICM Group study (1998), market share and customer satisfaction indicators, customer specific sales figures, and numbers of new customers, as well as markets. These indicators express a company's relationship to its customers, the most focal interest group in terms of revenue creation. Sveiby (1997) extends this customer-oriented approach on relational capital to also encompass the relationship of the company to its suppliers. In this study, we further extend variables to also capture relations to academia. For the process of value creation, bilateral access to synergetic and complementary research on a cooperative basis is a critical success factor for biotechnology companies as product development can be accelerated and modified in line with advancements in basic research. Close contact with academia also secures direct access to human capital within academia that can be directly utilized through cooperative arrangements, out-sourcing, or recruitment.

Since many of the biotechnology companies do not yet have customers, indicators like those suggested by the ICM Group (1998) above are not sensible from the perspective of validity. Nevertheless, we use a variable that depicts the companies' relationship to markets abroad, as the real potential for value creation resides not within domestic boundaries but on global markets. The variables used to proxy the relational capital of companies include (i) the share of exports of total turnover, (ii) the share of public R&D support used for university research, and (iii) a dummy variable indicating whether the companies' cooperate with a foreign university.

An additional dummy variable is inserted into the factor analysis in order to control for effects related to the unique characteristics of the pharmaceutical industry. Features of the pharmaceutical industry include very long product development phases and resource consuming drug approval processes. Thirty-five percent of the sample consists of companies active in the pharmaceutical industry.

In the descriptive statistics, the number of observations varies depending on the variable throughout Tables 1–5. Our intent is to provide maximum information at this stage. In the process of the factor analysis itself observations with missing values are automatically excluded and

Table 2 Descriptive statistics for variables measuring human capital (HC)

Variable	N	*Min*	*Max*	*Mean*	*Std. deviation*
Number of personnel (ln)	72	0.00	4.91	2.31	1.159
Share of doctors of total personnel	72	0.00	1.00	0.30	0.308
CEO's business experience (in years)	71	0.00	3.71	2.23	0.729
In-house marketing expertise	72	0.00	1.00	0.43	0.499

Table 3 Descriptive statistics for variables measuring structural capital (SC)

Variable	N	*Min*	*Max*	*Mean*	*Std. deviation*
R&D Costs per employee	72	0.00	1.40	0.07	0.186
Number of patents per Employee	72	0.00	21.43	0.81	2.665
Patent applications/(applications+patents)	71	0.0	0.92	0.31	0.297
Age (ln)	72	0.00	3.18	1.92	0.650

Table 4 Descriptive statistics for variables measuring relational capital (RC)

Variable	N	*Min*	*Max*	*Mean*	*Std. deviation*
Exports per turnover	71	0.00	1.00	0.37	0.411
Share of public support used for university research	69	0.00	1.00	0.23	0.305
Firm collaborates with a foreign university	69	0.00	1.00	0.13	0.650

Table 5 Descriptive statistics for control variable 'Pharma'

Variable	N	*Min*	*Max*	*Mean*	*Std. deviation*
Pharma (= 1)	72	0.00	1.00	0.35	0.479

N settles at 65 after the exclusion of seven observations. The results of the factor analysis are reported in more detail, together with the results of the regression analysis.

Table A1 (see Appendix A) displays the correlation matrix of all variables included in the factor analysis. The matrix facilitates a more elaborate and structured depiction of the underlying data. It also shows that the data is coherent in the sense that it displays patterns that are in line with common sense expectations.

For example, firms that employ experienced CEOs can be positively related to relatively large and old companies. They also correlate positively with relatively large revenue streams and cooperative links to academia in R&D. Furthermore, they have in-house marketing expertise. Firms that employ a relatively high share of doctors, on the other hand, are negatively related to firm size and in-house marketing expertise. These firms also less often have an existing product or service on the markets. Also, pharmaceutical companies can be associated with features that are rather plausible, namely, with relatively high R&D and labor intensities, high patent creativity, and collaborative arrangements with universities. They also have less often succeeded in bringing products or services to the market place.

Regression analysis and dependent variables

The purpose of the regression analysis is to test whether different IC configurations of companies affect their respective capital structure. Four different financial ratios are estimated using factor scores obtained in stage one of the analysis as independent variables: for each of the five factors obtained in the first stage of the analysis every observation receives a factor score, the value of which depends on how well the particular factor represents the particular observation.

Instead of estimating a simple debt-to-equity ratio, we scrutinize partial ratios for two reasons. First, testing Myers' (1984) pecking order hypotheses requires a more detailed analysis of the debt-to-equity ratio, including the separate identification of the share of internal equity, external equity, and debt of a firm's total financing. Second, as already concluded in Tahvanainen (2003) and Hermans (2004), the controversial features and a central role of capital loan financing in Finnish biotechnology necessitate its explicit and separate treatment. The estimated ratios include (i) the earnings, (ii) the external equity, (iii) the capital loan, and (iv) the debt ratio, (see Table 6).

The ratios are calculated as follows. The earnings ratio measures the degree to which operations are financed internally:

Table 6 Descriptive statistics for dependent variables

Variable	N	*Min*	*Max*	*Mean*	*Std. deviation*
Earnings ratio	67	−11.38	0.98	−0.82	1.917
External equity ratio	69	0.00	1.00	0.56	0.383
Capital loan ratio	69	−2.46	5.04	0.51	0.986
Debt ratio	69	0.00	1.09	0.37	0.339
Tangible assets ratio	69	0.00	0.75	0.14	0.164

$$\text{Earnings ratio} = \frac{\text{retained earnings}}{\text{total equity} + \text{total liabilities}}, \quad (1)$$

where total equity includes capital loans in accordance with Finnish accounting legislation, and total liabilities are corrected for accounts payable, as well as accrued charges and deferred credits. The correction of liabilities is performed because the above-mentioned balance sheet items do not express financing decisions that have been made explicitly and strategically, but are the sheer result of the size, volume, and life cycle effects of the business.

External equity is the share of adjusted total equity owned by individuals or organizations not being actively involved in the daily business of the company of which they are shareholders.

$$\text{External equity ratio} = \frac{\text{external equity}}{\text{Adjusted total equity}}, \quad (2)$$

where adjusted total equity is computed from total equity by subtracting capital loans and retained earnings from it. Additionally to retained earnings, we exclude capital loans from total equity prior to any ratio computations to avoid potential distortions caused by the controversial features of capital loans that, although legally treated as equity, show many characteristics of debt financing. Retained earnings are an internal source of equity. Thereby, the definition of adjusted total equity in this study matches that of equity in the pecking order literature as closely as possible.

Capital loan ratio is calculated as follows:

$$\text{Capital loan ratio} = \frac{\text{capital loans}}{\text{adjusted total equity} + \text{total liabilities} + \text{capital loans}}, \quad (3)$$

where the definitions of elements comply with those already treated above. It should be pointed out that retained earnings are left out of the equation intentionally, because a number of companies display negative earnings so large that their unadjusted total equity (without capital loans) is negative. Computing a ratio thereof does not provide results with interpretative value. As stated by Tahvanainen (2003), capital loans as a source of financing deserve and require a separate examination due to their hybrid nature, combining features of equity and debt. The treatment of capital loans as an integral part of equity might result in distortions that render the

results of the analysis worthless. Debt ratio is denoted as:

$$\text{Debt ratio} = \frac{\text{total liabilities}}{\text{adjusted total equity} + \text{total liabilities} + \text{capital loans}}, \quad (4)$$

where definitions of elements comply with those already treated above. Again, the problematic effects of retained earnings are corrected for by excluding them from the computation.

As already discussed, the factors of the analysis in stage one represent generative intangible assets. According to the framework presented in Figure 2, investors infer the value of a company by taking its tangible assets into account. Therefore, we include a separate variable indicating the share of tangible assets of the balance sheet total into the regression.

In order to estimate the effects of different IC configurations and tangible assets on the above ratios, the independent variables are inserted into a linear regression model using the OLS method. The model is run separately for all four ratios. The formal expression of the model takes the following form:

$$D_i = \alpha + \beta I_i + \delta C_i + \varepsilon_i, \quad (5)$$

where D represents the dependent variable, here the various capital ratios. The constant is represented by the term α in the formula. The independent variables, here the factor scores, are incorporated into the model by the vector I. The regression coefficient of the vector I is denoted as β. C is the control vector representing control dummies and other controls. The term δ is the coefficient of the vector C. The error term is marked by ε and the subscript index i serves as the firm index.

Results

Figures 3–6 display the combined results of the factor and regression analyses. They present the statistically significant variables that particular factors consist of and the relationship of these factors to the capital structure ratios introduced above. Separate and comprehensive results for both analyses are provided in Tables A2 and A7 in the Appendix A.

Earnings ratio

Figure 3 shows the factors that interact with the earnings ratio. Two out of five factors explained the variation in the ratio significantly, namely factors 1 and 4. Factor 1 represents firms with a well-balanced IC base. All three IC components are present with the CEO's experience embodying human capital, the age of firms representing structural capital, the export ratio standing for relational capital and turnover as well as the product-on-markets indicator representing commercially exploitable intangible assets. At this point, one should point out that factor 1, the only factor representing a well-balanced IC base, is the sole factor comprising commercially exploitable intangible assets.

Firms that are represented by factor 1 display a higher earnings ratio. The coefficient of the regression analysis is positive and statistically significant at the 10% level.

Factor 4 represents firms with an incomplete IC base having only structural capital. In factor 4, structural capital is expressed by the variables indicating the ratio of patent applications of the total patent portfolio and the R&D intensity. Firms represented by factor 4 show a negative relationship to the earnings ratio. The coefficient is significant at the 10% level.

In other words, these findings indicate that the most research intensive and innovative firms have been unable to generate significant cash flows.

External equity ratio

Figure 4 shows the results for the external equity ratio. Factor 2 is the only factor explaining the ratio. It represents an incomplete IC base having only human and relational capital. In factor 2, human capital is expressed by the number of personnel, in-house marketing experience, and the share of doctors of total personnel, where the share of doctors is in a negative relationship to the other variables. Relational capital is expressed by the variables indicating collaboration between a firm and a foreign university. Firms represented by factor 2 have a higher external equity ratio. The coefficient is significant at the one percent level.

The results for factor 2 can also be interpreted inversely, negating all coefficient fore signs. Then factor 2 would represent firms with few personnel, no marketing experience, a high share of doctors, and no collaborative arrangements with foreign universities. Firms represented by this inverse factor 2 have a lower external equity ratio.

One can also argue that those firms, that have obtained financing in terms of external equity have been able to increase their size. Or, investors have steered these firms to recruit people with marketing competencies. Such problems of reverse causality or simultaneity bias will be further discussed below.

Capital loan ratio

Figure 5 presents the results for the capital loan ratio. Again, factors 1 and 4 affect the ratio. Firms with a well-balanced IC base represented by factor 1 are negatively correlated to the capital loan ratio, whereas firms represented by factor 4 have a higher capital loan ratio. The coefficient of factor 1 is significant at the one percent level and the coefficient of factor 4 at the five percent level.

Young and research intensive firms, which have an inexperienced CEO and which have not generated sales or exports, do have relatively high capital loan injections. This stresses the significant role of the Finnish government in the financing of the infant industry given that the government has provided more than half of the industry's capital loans (Hermans & Tahvanainen, 2002; Tahvanainen, 2003; Hermans, 2004).

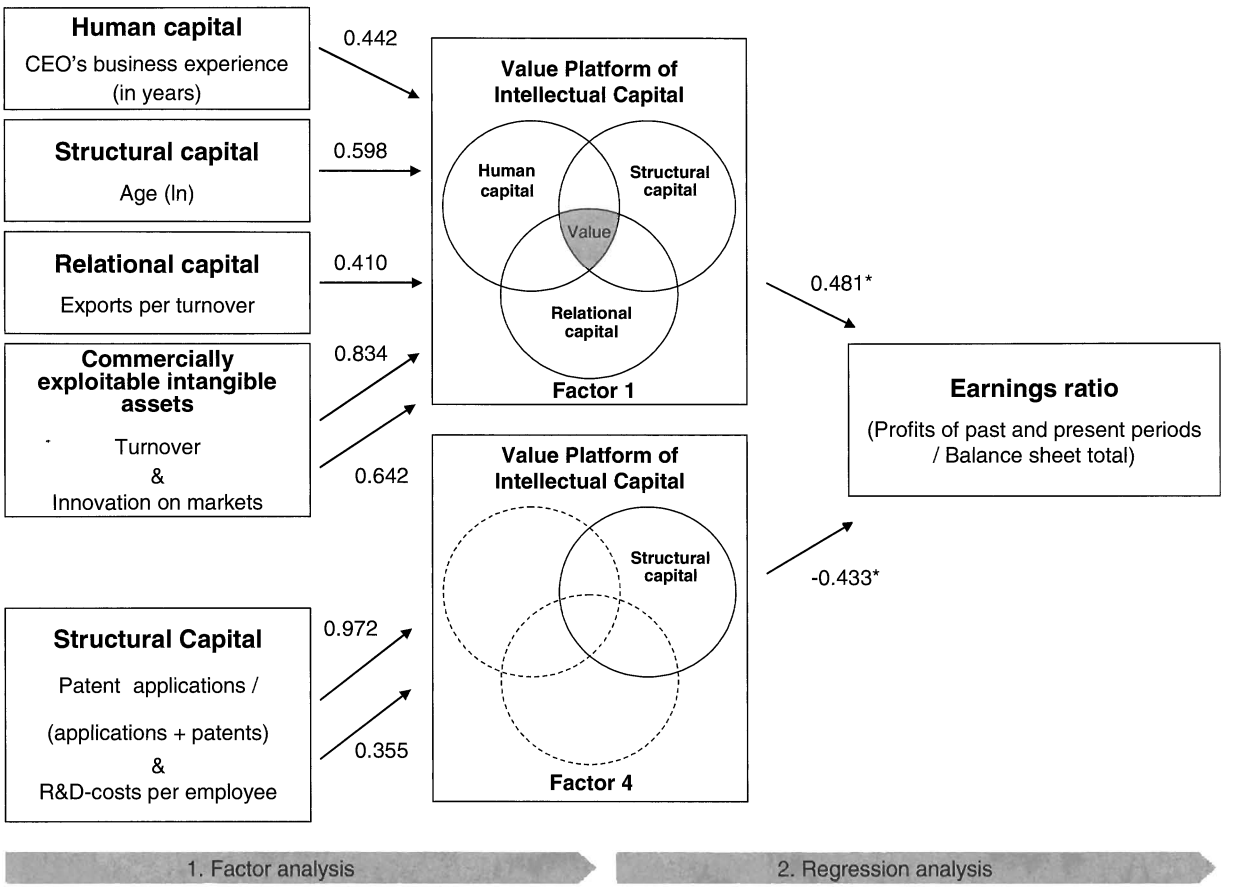

Figure 3 Factors interacting with the earnings ratio.

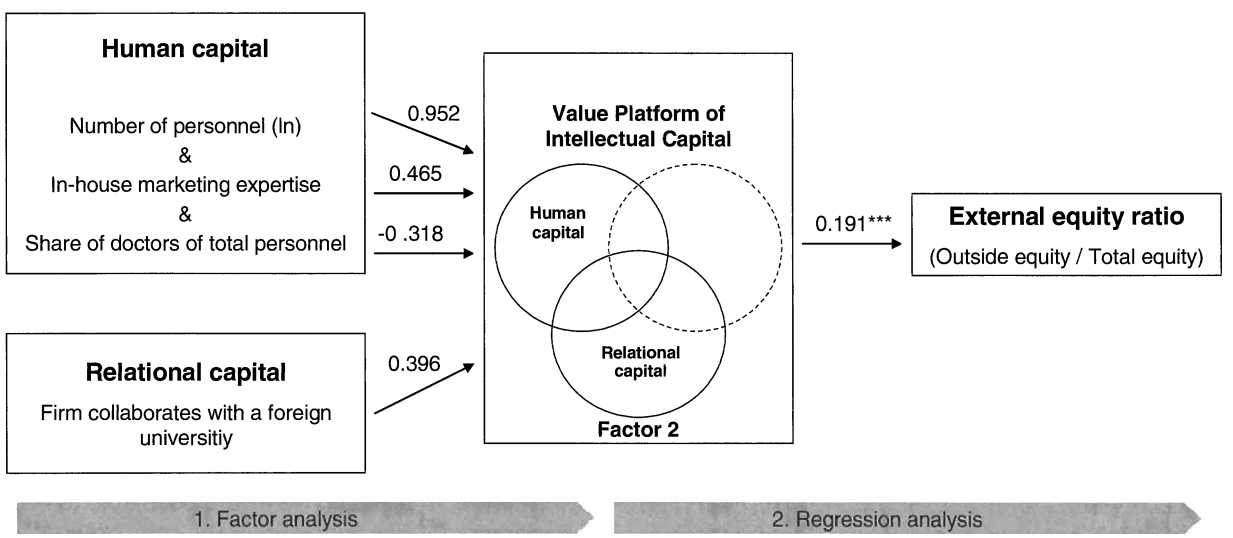

Figure 4 Factors interacting with the external equity ratio.

Debt ratio

Figure 6 shows results for the debt ratio. Factors 1 and 4 are the sole factors with explanatory power. Well-balanced firms show a positive affiliation to the debt ratio with the coefficient being significant at the one percent level. Firms represented by factor four are negatively correlated to the ratio. The coefficient for factor 4 is negatively significant at the 5% level.

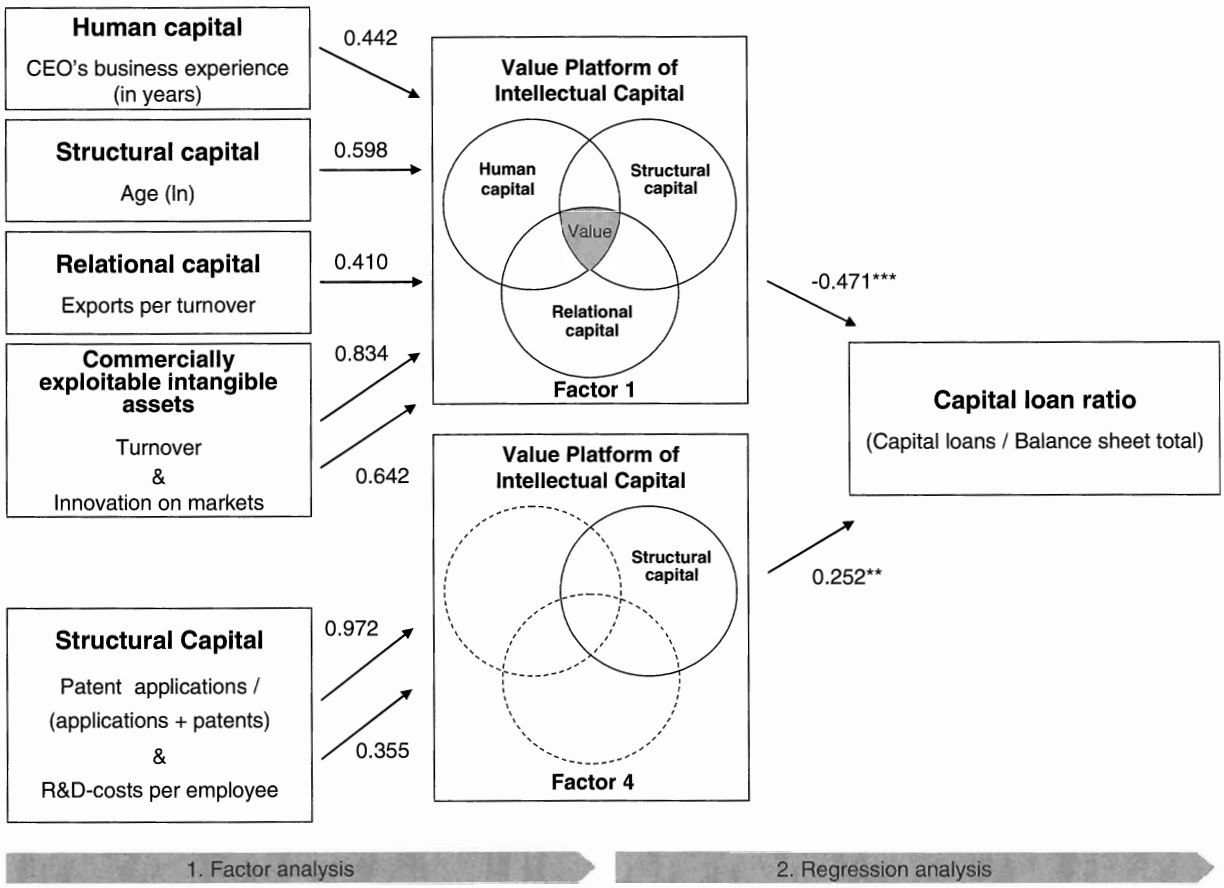

Figure 5 Factors interacting with the capital loan ratio.

When the firm is mature and has already generated sales, it can obtain debt financing. If the firm's only collaterals are based on structural capital, here the research activities, it seems difficult to acquire any debt.

Discussion

Based on the empirical evidence, we find that there is a relationship between the IC and the financial capital structure of a company. In the following sections we discuss two alternative interpretations of this relationship, one of which favors the financial pecking order framework introduced earlier in the paper, whereas the other is in line with empirical research countering the theory.

The results can be argued to be in line with Myers' (1984) pecking order framework insofar that firms of high value displaying a well-balanced IC base (factor 1) shun external equity financing and display higher retained earnings and debt ratios than other types of firms. According to the perspective of the pecking order hypothesis, this behavior aims at avoiding the undervaluation of equity. Also in line with the hypothesis, firms of allegedly lower value (factor 2) utilize relatively more external equity financing as their equity is not as severely undervalued. Firms with only a single IC component, here structural capital related to research intensity and innovativeness (factor 4), prefer capital loans as a source of financing relatively more than other firms. Capital loans are a special feature of the Finnish financial markets and play a decisive role in the financing of the biotechnology industry. Thus, they deserve separate treatment.

Assuming that the pecking order hypotheses is indeed the driving force behind the findings, this implies that the information asymmetry between the sample firms and financial markets truly exists, and that a strong IC base does not positively affect the availability of financing. If the IC base of companies was observable and it revealed the true value of a company by nullifying the information asymmetry, we would be unable to evidence a pecking order-like behavior, as the companies' equity is always priced fairly on markets making firms indifferent between financing sources.

The findings render false our claims concerning the active use of knowledge management metrics. Either (a) intangible assets are unobservable or (b) investors simply do not bother to apply information beyond leadership, management, and tangible assets when evaluating com-

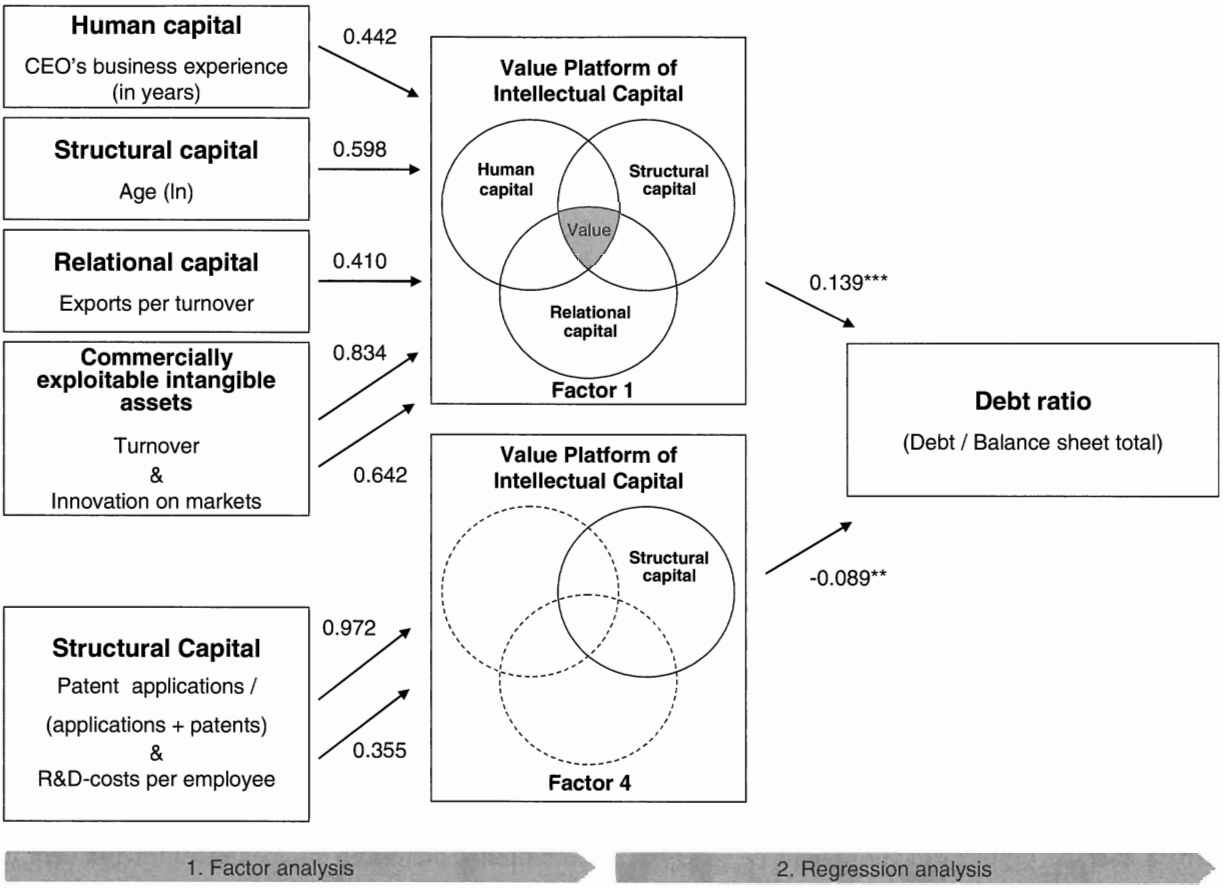

Figure 6 Factors interacting with the debt ratio.

panies, as Hussi (2004) states. As comprehensive knowledge management metrics do exist and are retrievable from target companies in conjunction with the customary Due Diligence analysis prior to investment, the former notion is hardly defendable. Thus, the latter is the more credible explanation and constitutes a challenge for those aiming to promote knowledge management beyond the boundaries of scientific discussion and towards its application in the field.

Issues of reverse causality

As pointed out above, the study leans on cross-sectional data. This confronts us with a reverse causality problem. We cannot definitely show whether a company's capital structure is determined by its IC base or whether financing comes with constraints that force a company to adapt its IC base accordingly. Thus, the validity of the discussion above rests very much on the validity of the pecking order hypothesis. The theory implies that the decisions from which source and to what extent financing is to be drawn are made actively by the companies that, for their part, optimize the cost of financing. Thus, according to this notion, a company's IC base explains its capital structure as interpreted above.

Nevertheless, blindly taking the theory's perspective as given might oversimplify reality. It is assumable that biotechnology firms, in their infant stage, are not in the position to choose freely from different sources of financing to the extent that knowledge-intensive operations require. In fact, in the start-up phase, companies are usually happy to receive any financing, regardless of the terms with which it comes. As soon as the founding capital is consumed, these companies usually turn to venture capitalists and other external equity sources in the hope of getting financed, as the debt market is still out of reach due to a lack of collaterals and revenue streams (see Graham & Harvey, 2001; Frank & Goyal, 2003). In this situation, the pecking order is reversed (Hyytinen & Pajarinen, 2002). In contrast again, Fama & French (2002) present empirical results on how the debt market can be utilized for the short-term needs of financing even when the external equity financing is preferable in the long run.

The stage in the life cycle of a firm might not have an effect only on the validity of the pecking order theory, but also on the direction of causality between the IC base and the capital structure of a company. Knowing that investors, especially venture capitalists, apply harsh direct regulation on the companies in which they invest, receiving financing from external sources will most probably have an effect on company structures and thereby also on the IC base of companies. Young

Table A1 Correlation matrix for variables included into factor analysis

Variable code	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*
1	1														
2	−0.341**	1													
3	−0.072	0.298*	1												
4	−0.318**	0.500***	0.309**	1											
5	0.134	0.123	0.137	0.173	1										
6	0.055	−0.149	0.085	0.031	−0.028	1									
7	−0.092	0.153	0.419***	0.083	0.036	0.105	1								
8	−0.173	0.230	0.079	0.273*	0.369**	−0.051	−0.184	1							
9	−0.091	0.232	0.099	0.006	0.142	0.018	0.352**	0.075	1						
10	−0.192	0.263*	0.300*	0.318**	0.000	0.351**	0.144	0.082	0.051	1					
11	−0.102	0.346**	0.090	0.212	0.125	0.108	−0.045	0.235*	−0.046	0.360**	1				
12	−0.291*	0.050	0.190	0.104	−0.089	0.094	0.238*	−0.133	0.162	−0.105	−0.134	1			
13	0.189	0.244*	−0.051	−0.045	0.276*	0.176	−0.106	0.202	−0.087	0.139	0.199	−0.326**	1		
14	−0.117	0.154	0.165	0.151	−0.041	−0.026	0.107	−0.152	−0.079	−0.073	−0.088	0.107	−0.094	1	
15	−0.168	0.306*	0.282*	0.088	−0.076	−0.010	0.417***	−0.159	0.349**	−0.189	−0.115	0.534***	−0.187	0.263*	1

***Correlation is significant at the 0.001 level (two-tailed), **correlation is significant at the 0.01 level (two-tailed), *correlation is significant at the 0.05 level (two-tailed).

Variable code legend:

1 doctors/personnel, 2 ln personnel, 3 Ceo's experience in years (ln), 4 full-time marketing expertise, 5 RD/personnel, 6 patents/total personnel, 7 age (ln), 8 patent applications/(patent applications+patents), 9 exports/turnover, 10 share of public support used for university research, 11 collaboration with foreign university, 12 innovation to markets within past 3 years, 13 pharma = 1, 14 sales/personnel, 15 turnover € (ln).

Table A2 Rotated factor matrix

	Factor				
Variable	*1*	*2*	*3*	*4*	*5*
LnTurnover €	0.834				
Innovation to markets within past three years	0.642				
LnAge	0.598				
LnCeoexperience	0.442				
Exports/turnover	0.410				
Sales per personnel					
LnPersonnel		0.952			
Full-time marketing expertize		0.465			
Collaboration with Foreign University		0.396			
Post-graduated personnel/total personnel		−0.317			
Share of public R&D support used in university research			0.887		
Patents/total personnel			0.522		
Patent applications/(patent applications+patents)				0.972	
RDperpersonnel				0.355	
Pharma = 1					0.969

Extraction method: generalized least squares. Rotation method: varimax with Kaiser normalization.

Table A3 Communalities for factor analysis

Variable	*Initial*	*Extraction*
Post-graduate personnel/total personnel	0.367	0.457
LnPersonnel	0.595	0.999
LnCeoExperience	0.347	0.460
Full-time marketing expertize	0.396	0.453
RDPerpersonnel	0.291	0.382
Patents/total personnel	0.340	0.417
LnAge	0.407	0.523
Patent applications/(patent applications+patents)	0.352	0.999
Exports per turnover	0.335	0.478
Share of public R&D support used in university research	0.476	0.861
Collaboration with foreign university	0.308	0.368
Innovation to markets within past three years	0.452	0.586
Pharma = 1	0.432	0.999
SalesPerPersonnel	0.181	0.259
LnTurnover €	0.563	0.779

Extraction method: generalized least squares.

Table A4 Total variance explained (factor analysis)

	Initial eigenvalues			*Extraction sums of squared loadings*			*Rotation sums of squared loadings*		
Factor	*Total*	*% of variance*	*Cumulative %*	*Total*	*% of variance*	*Cumulative %*	*Total*	*% of variance*	*Cumulative %*
1	2.939	19.590	19.590	1.930	12.867	12.867	2.063	13.754	13.754
2	2.413	16.084	35.674	1.035	6.902	19.769	1.646	10.973	24.727
3	1.507	10.045	45.719	1.711	11.409	31.178	1.397	9.314	34.041
4	1.417	9.445	55.164	1.375	9.165	40.343	1.238	8.252	42.293
5	1.139	7.591	62.755	1.526	10.174	50.517	1.234	8.224	50.517

Extraction method: generalized least squares.

Table A5 KMO and Bartlett's test

Kaiser–Meyer-Olkin Measure of Sampling Adequacy		*0.576*
Bartlett's test of sphericity	Approx. χ^2	233.488
	df	105
	Sig.	0.000

The KMO measure of sampling adequacy does not quite meet the limit of 0.600, which is conventionally held as a critical value. However, Bartlett's test of sphericity shows that a factor analysis can be applied on the data at a 0.1 percentage risk level.

Table A6 Goodness-of-fit test

χ^2	*df*	*Sig.*
28.255	40	0.918

The goodness-of-fit test implies that the factor solution is able to explain the variance of initial variables.

Table A7 Results for the regression analysis

Dependent variable:	*Earnings ratio*	*External equity ratio*	*Capital loan ratio*	*Debt ratio*
R^2	0.171	0.325	0.168	0.251
Adjusted R^2	0.083	0.255	0.082	0.174
F-test	1.956*	4.645***	4.126*	3.244***
Variable	β	β	β	β
Constant	−0.773**	0.569***	0.242***	0.330***
	(0.322)	(0.055)	(0.047)	(0.053)
Factor 1:	0.481*	0.041	−0.090**	0.139***
HR+SC+RC+CEIA	(0.258)	(0.045)	(0.038)	(0.042)
Factor 2:	−0.308	0.191***	0.019	−0.002
HC+RC	(0.251)	(0.043)	(0.037)	0.041
Factor 3:	−0.267	0.065	−0.037	−0.022
SC+RC	(0.251)	(0.044)	(0.037)	(0.041)
Factor 4:	−0.433*	−0.021	0.070**	−0.089**
SC	(0.236)	(0.041)	(0.034)	(0.039)
Factor 5:	0.347	0.027	0.001	0.008
Pharmaceuticals	(0.239)	(0.041)	(0.034)	0.039
Tangible assets	−0.549	0.105	−0.036	0.278
	(1.517)	(0.263)	(0.221)	0.250

Standard errors in parentheses. Asterisk labels (*) stand for level of statistical risk of rejecting the null hypothesis incorrectly. (*) 10 per cent, (**) 5 per cent, (***) 1 percent risk level.

About the authors

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Appendix 6. Value Creation Potential of Intellectual Capital in Biotechnology

Hermans, R. – Kauranen, I. (2005). Value Creation Potential of Intellectual Capital in Biotechnology: Empirical Evidence from Finland. *R&D Management*, vol. 35, 171-185.

Value creation potential of intellectual capital in biotechnology – empirical evidence from Finland

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The objective of the study was to empirically verify impacts of intellectual capital (IC) to the anticipated future sales of small- and medium-sized companies within the biotechnology industry. The study creates and develops tools for the valuation of companies by relating the existing intangibles and the expected value creation of the companies in that industry displaying high growth prospects but long and insecure product development phases. Theoretically, IC is divided into the following three categories: human capital (HC), structural capital (SC), and relational capital (RC). In the empirical setting, survey data of small- and medium-sized Finnish biotechnology companies are used. In the econometric analyses, the interactions, or empirical co-variation, between the three categories of IC explain two-thirds of the variance in the anticipated future sales of the sample companies. Thus, it seems that a well-balanced combination of HC, SC, and RC implies value creation potential and high anticipated future sales.

1. Introduction

1.1. Background

In the valuation of a company or a single business project, prevailing methods in accounting and finance are based on assessing the worth of today's investment in relationship to the positive cash flows in the future. The net present value of the project or the company is derived from these future cash flows. Strictly speaking, the net present value of the investment is the difference between the discounted, or present, value of the future income and the amount of the initial investment (see e.g. Brealey and Myers, 2003). Both theoretically and in practice, the valuation of on-going companies or business projects is linked, instead of their liquidation value, to their ability to generate positive cash flows in the future.

In management literature, the value of companies is often explained by the impact of intellectual capital (IC) (e.g. Edvinsson and Malone, 1997; Sveiby, 1997; Hall, 2001; Mayo, 2001). Adequate IC enables the company to create innovations and to exploit them commercially. This is a prime source for future sales, especially in high-technology industries.

The anticipated future sales determine the market valuations of companies. High present value estimates are characteristic of industries

that have high prospects for future sales. The biotechnology industry is an archetype of industries with prospects for extraordinary high future sales. Because of its good future prospects, the biotechnology industry has attracted large infusions of private venture capital. Government agencies enhancing promising industries have also heavily supported the development of biotechnology.

Despite the high impact of IC on the anticipated sales and, accordingly, on the valuation of companies, there have been only a few empirical contributions on these matters in knowledge-management literature. Attempts to empirically measure the impact of IC on value creation have been rare (Gu and Lev, 2001). Even though the biotechnology industry offers tempting future prospects and sets demanding challenges for venture capital industry and for public industry-development agencies, there is a lack of research studies exploring the special characteristics of companies in the biotechnology industry (Cumby and Conrod, 2001).

1.2. The objective and scope of the study

The fact that the market valuation of companies is mainly based on anticipated growth prospects challenges the reliability of the anticipated future cash flows disclosed by the companies. This study attempts to offer a tool on how these speculative future prospects can be assessed in a way that controls for individual and subjective biases of future anticipations. The IC framework offers insights in how the present resources of companies can be used in empirical evaluations of future anticipations disclosed by the companies themselves. This is especially relevant in growth-oriented industries such as the biotechnology industry.

The objective of the present study is to empirically verify impacts of IC to the anticipated future sales of small- and medium-sized enterprises within the biotechnology industry. It is important that the drivers behind the business logic and the valuation of companies within the biotechnology industry can be well understood. The present study combines the econometric discipline of research methods and knowledge-management research traditions to reach the present research objective (Figure 1).

The present study employs a good representative survey sample of small- and medium-sized Finnish biotechnology companies. The interviews

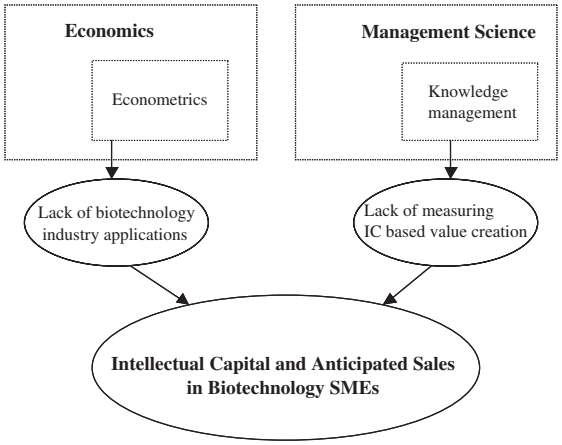

Figure 1. The positioning of the present study in relationship to different research methods and research traditions (IC, intellectual capital).

were carried out at the beginning of 2002.[1] Many of the Finnish biotechnology companies are research-based spin-offs, having at the time of the interviews low or no sales. The sample of companies constitutes a good case for studying how anticipated future sales and corresponding valuations are built on the IC of the companies. Accordingly, in the present study, we empirically test the IC approach presented in knowledge-management literature (e.g. Edvinsson and Malone, 1997; Stewart, 1997; Sveiby, 1997; Ahonen, 2000; Hussi and Ahonen, 2002) by applying statistical tools.

2. Theoretical background

Knowledge-management literature has flourished since the mid-1990s. Nonaka and Takeuchi (1995) laid a foundation in the discussion on knowledge creation in companies. In the literature, the IC of the companies was used as an explanation for the fact that the book values of companies are often lower than the market valuations of the companies. (Edvinsson and Malone, 1997; Stewart, 1997).

In the knowledge-management literature, IC is usually grouped into three partly overlapping categories. For example, Sveiby (1997) defines the following three categories: individual competencies, internal structures, and external structures. Saint-Onge, Armstrong, Petrash, and Edvinsson (in Edvinsson and Malone, 1997) list the following three categories: human capital (HC), organizational capital, and customer capital respectively. Hussi (2001) and Hussi (2003)

combine these definitions and put forward the idea that IC contains the following three categories: HC, internal structures, and external structures. Hussi argues that the category of individual competencies is too narrow a definition for HC. According to Hussi, HC contains other aspects besides individual competencies. Such additions can include, for example, the health of individuals. On the other hand, external structures can include a wider scope than only customer relations. For example, many companies are closely linked to their suppliers or academic research networks.

In the present study, we apply a recent consensual definition of IC (e.g. Bontis, 2002a; MERITUM Project, 2002), which also groups IC into three categories (Figure 2). The first category is HC, which is composed of the skills and competencies of the company's personnel. The second category is structural capital (SC), which signifies the company's ability to organize its activities in a way that tacit knowledge can be converted into intellectual property rights owned by the company.[2] The third category is relational capital (RC), which stresses the importance of external networks, for example, with customers and other partners. According to the knowledge-management approach, when there is close interaction between these three categories of IC, the firm is able to create value from its business activities and growth can be anticipated. A well-balanced combination of HC, SC, and RC is needed and this requires proper knowledge management. For example, even if a company has ample HC represented by labor with a high level of expertise, the value creation is not guaranteed if production or marketing processes are not well organized or customers are not reached.

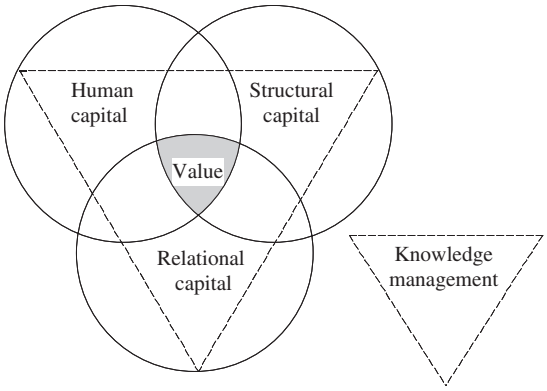

Figure 2. Intellectual capital and knowledge management, modified from Saint-Onge, Armstrong, Petrash, and Edvinsson in Edvinsson and Malone (1997).

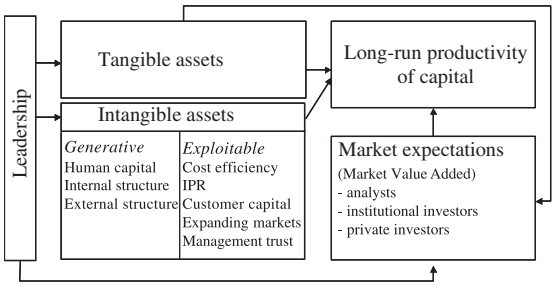

Figure 3. Intangible assets and long-run productivity of capital (Ahonen, Hussi, and Asplund in Hussi 2001).

Ahonen (2000) and Ahonen, Hussi, and Asplund (in Hussi, 2001) deepen the description behind the value-creation mechanism (Figure 3). They divide intangible assets (IAs) into generative assets and commercially exploitable IAs. The scheme in Figure 3 emphasizes generative IAs as an enabler in the development of commercially exploitable IAs. The commercially exploitable IAs, in turn, enable the present value creation. The value creation is depicted as the interaction between HC, SC (internal structure), and RC (external structure) in Figure 2. Generative IAs prepare the way for the commercially exploitable IAs in the future and affect long-run productivity of capital in Figure 3.

3. Data and research methods

3.1. The survey companies

At the end of 2001 there were approximately 120 actively trading biotechnology companies in Finland (Kuusi, 2001; Hermans and Luukkonen, 2002). The companies were interviewed by telephone in the spring of 2002 and sufficient data were obtained from 84 companies. Of the companies interviewed, 12 companies were classified as large companies. A company was classified as a large company if two out of the following three conditions were fulfilled: the company had more than 250 employees, its sales was more than 40 million euros, or its total balance sheet exceeded 27 million euros. Thus, 72 of the interviewed biotechnology companies were small- or medium-sized and formed the research sample of companies.

Using only small- and medium-sized companies in the study increases the reliability of the study. Many of the large companies are multifunctional, with only a (small) part of their sales coming from biotechnology products. Also, some of the large

sample companies are a part of a consolidated company and their financial reports are not given in a uniform manner.

The survey data included information about ownership, financial accounting, input–output networks, as well as research and development (R&D) activities. The survey also included the company managers' anticipations on the future development of the companies. The survey contained 120 questions of which about one-third are used in the present study.

Specific measures were taken in order to get undistorted answers from the company managers. For example, at the beginning of each interview, a confidentiality assurance was given to the respondents, assuring, for example, then no data that could identify a single company would be published. The psychological implications behind the sales anticipations would be an interesting research topic in itself, but in the present study, these anticipations are taken as given.

3.2. Variable construction

In the present study, we follow the definition of IAs presented in Figure 3, in which IAs are divided into two categories: generative IAs and commercially exploitable IAs. The amount and quality of generative IAs are measured in the present empirical study by several variables describing IC. Commercially exploitable IAs are measured by the present sales of the companies. Accordingly, by studying separately generative IAs and commercially exploitable IAs, we can identify the impact that these two categories of assets have on anticipated sales. In the present study, IAs are studied using stocks but IC is studied through interaction (see e.g. Hussi, 2003).

Many of the values of the variables in the present study have a very wide distribution and the distributions can be skewed. This can distort such analyses, which are based on linear correlations. Thus, as a common research procedure, variables are logarithmized before performing the analyses. This transformation is not needed for such variables, which are ratios or dichotomous dummy variables.

3.2.1. Generative IAs. Variables to measure generative assets are constructed mainly based on Sveiby's (1997) notion that IC can be measured by using three categories of variables, namely

(a) growth and renewal;
(b) efficiency;
(c) stability.

In the biotechnology industry, large investments have been made in intensive R&D activities to commercialize innovations or sell intellectual property rights. Only a few of the anticipated potential innovations have been successfully developed, and even fewer of them commercialized. Thus, the importance of efficiency and stability is not as remarkable as it is when there is something to sell. Accordingly, in the present study, the focus is on the first category of variables, growth and renewal.

IC is grouped into three categories: HC, internal capital, and RC. These categories are used when conceptualizing the variables in the theoretical knowledge-management framework. Theoretically, the interactions between HC, internal capital, and RC are important in the value creation in companies. These categories of IC can be applied at the firm level (Mouritsen et al., 2000) and at the economy level, representing groups of companies (Bontis, 2002b). The econometric procedures can be based on the viewpoint of the business-management literature, and the variables of knowledge-management models can be linked to data on the biotechnology industry.

3.2.1.1. HC. HC is more central to the core of IC than the two other categories of IC (Edvinsson and Malone, 1997). We modify Sveiby's (1997) classification in the construction of the three variables, which we will use to measure HC in the companies (see Table 1):

Table 1. Description of the HC variables.

Statistics	*N*					
HC	Valid	Missing	Mean	Median	Standard deviation	Sum
Personnel	72	0	29.4	8	104.4	2,119
Doctors and licentiates	72	0	3.0	2	3.8	215
CEO's business experience in years	71	1	10.6	10	7.6	756

HC, human capital.

(a) the total personnel;
(b) the education level of the personnel (the number of persons holding doctoral licentiate degrees);
(c) the business experience of the CEO (in years).

The total personnel measure the quantity and the critical mass of HC in the companies. Biotechnology is a knowledge-intensive industry and, thus, the total personnel is a relevant variable measuring the critical mass of HC. The number of personnel in the companies is connected to the age of the companies within the data. On the one hand, over half of the youngest companies in the sample employed less than 10 persons. On the other, almost half of the oldest companies had more than 250 employees.

The two other variables attempt to capture features describing the quality and the skills of the personnel. The education level of the personnel measures the general quality of the HC and the specific quality of the HC in the form of the research training of the personnel. This variable measures the formal knowledge stock and the ability to process the knowledge stock.

The business experience of the company's CEO attempts to measure the skills related to business performance. It is interesting to note that the youngest biotechnology companies have hired many employees with doctoral degrees but CEOs with doctoral degrees do not have long careers in business.

3.2.1.2. SC. SC includes the way of organizing the company's activities and also the intellectual property rights of the company. The present study operates with three variables describing SC:

(a) R&D input (R&D costs in euros);
(b) patent intensity (the number of patent applications and patents);
(c) the age of the firm (in years).

In the present study, we deviate from the mainstream measures (Sveiby, 1997), which focus on the information technology inputs. However, Deeds (2001) brings out R&D expenditure as a focal source of innovation potential. Within the data at hand, R&D intensity is strongly connected to the age of the companies. Over half the young companies spend over 50% of their total expenditure on R&D activities. This expresses clearly the nature of the biotechnology industry. Companies, which had a low R&D expenditure percent, were on average older than other companies in the sample. Such older companies were often owned by other non-financial companies.

Lev and Sougiannis (1998) discuss the impacts of different reporting methods on the relation of R&D expenditure and realized earnings. In the present study, we do not use figures taken from the official accounts of the companies, but rather figures given directly by the companies in the interviews. In Ahonen's (2000) terms, R&D expenditure can be held as a generative IA whereas the patent portfolio is a commercially exploitable IA. A key question related to a company's SC and value creation is how its R&D expenditure can generate patent applications and patents that are commercially exploitable. Stewart (1997) also highlights the intellectual property rights as a way to create value with (internal) SC (see Table 2). The number of patents and patent applications is used to measure the future potential of the company. However, the interaction between the internal capability to produce patent applications and the external regulatory environment is essential. Because the variable measuring patenting intensity is the quantity of patent applications and the patents a company holds, it also reflects the future sales potential arising from the innovation portfolio of the company.

The age of the company is employed as a variable measuring SC. Some factors, for example, the stability of the organizational structures are often difficult to measure, and they can be quantified by using age as an estimator (Sveiby, 1990, 1997). The age of the company can affect how the internal affairs have been organized in a company in many ways. Organizational cultures differ from each other in old companies,

Table 2. Description of the SC variables.

Statistics	*N*					
SC	Valid	Missing	Mean	Median	Standard deviation	Sum
Research and development costs in million euros	72	0	1.39	0.17	3.40	100.34
Patents and patent applications	72	0	11.8	4	26.6	849
Age of company	72	0	7.2	6	4.9	521

SC, structural capital.

Table 3. Description of the RC variables (in millions of euros).

Statistics	*N*					
Million euros RC	Valid	Missing	Mean	Median	Standard deviation	Sum
University research and development in collaborating projects	68	4	0.11	0.001	0.36	7.66
Equity financing from individuals active in business	71	1	0.42	0.03	1.37	29.96
Equity financing from other non-financial companies	72	0	0.56	0.00	2.28	40.04
Equity financing from private venture capital companies	72	0	0.41	0.00	2.12	29.23
Equity financing from governmental venture capital institutions	72	0	0.35	0.00	1.44	25.46
Capital loan financing from private venture capital companies	71	1	0.28	0.00	1.00	19.69
Capital loan financing from governmental venture capital institutions	70	2	0.56	0.02	1.70	39.54

RC, relational capital.

on the one hand, and in young companies, on the other.

Age can also contain some other specific features with high relevance to market valuation and sales potential. For instance, the drug development process carries out a tightly regulated drug approval process with pre-clinical and clinical phases (1–3). Furthermore, even if a drug is approved, it will not self-evidently become a bestseller in the marketplace. It can be expected that when the company passes a single phase of the approval process, this affects positively the anticipations of the future sales and, thus, the valuation of the company.

However, only 35% of the companies in the sample have disclosed that their core business is drug development. Thus, in order to control for the impact of special features within the drug development business, we added dummy (0–1) controlling variables into the analysis. These variables indicate whether a single company belongs to some specific branch ($=1$) or not ($=0$). Accordingly, we were able to control for the impact of differences of business logics within separate branches (pharmaceuticals, diagnostics, biomaterials, industrial enzymes, food and feed, agro, services, other).

3.2.1.3. RC. Edvinsson and Malone (1997) and Stewart (1997) define the company's RC as customer capital. Sveiby (1997) also takes into account supplier networks in relational structures. Market potential and catering to customer needs are fundamental requirements for success in any business. Most of the future of the market potential in small open economies results from the anticipated sales in international markets. Foreign exports are, thus, essential to companies acting in a small open economy that does not have a large home market, and the anticipated future sales of companies can be related to their plans to internationalize their operations. The present level of foreign exports varies among different age groups of the sample companies. The younger sample companies, in particular, anticipate a relatively rapid increase in their exports in the future. Accordingly, the demand-pull of the global markets can be considered a key external driver for anticipated future sales of the Finnish biotechnology companies. However, the variable 'anticipated change in exports' is not utilized in the present study because of a simultaneity and feasibility problem. Anticipated exports growth is deemed to occur simultaneously with anticipated sales growth. Both are based on the companies' own articulations and this could raise a danger of explaining anticipations by anticipations from the same source.

Many of the early-stage biotechnology companies have no customers. Thus, their success rests on future anticipations. Potentials in R&D increase a company's anticipated sales that, in turn, draw financial investments necessary to continue R&D activities aiming at commercialization. When speaking of the early-stage biotechnology companies, a most important aspect of RC is R&D collaboration and investor networks. A strong science base is necessary in order to attract large investments (Darby and Zucker, 2002).

In order to obtain financing, the company should be credible and trustworthy in the investors' eyes. Guiso et al. (2001) state, '*Whether such an exchange [financing] will take place depends upon not only the enforceability of contracts, but also the extent the financier trusts the financee. Thus, higher level of trust improves the efficiency of*

financial contracts and increase their use.' In this sense, the definition of RC above is closely related to the concepts of social capital and trust.

RC is measured in the present study by seven variables, which are divided into the following three groups (see Table 3):

(a) university collaboration intensity (university R&D paid from governmental R&D support in euros);
(b) sources of equity financing (in euros, equity financing received from individuals active in business, private venture capitalists, governmental venture capitalists, and other firms);
(c) sources of capital loan financing (in euros, capital loan financing received from private venture capitalists and governmental venture capitalists).

The equity financing from persons who are actively involved in business, private and governmental venture capital institutions, and other firms measures ownership structures. Hermans and Tahvanainen (2002) showed that the ownership-related variables are loaded with expectations for value creation. Some investors are willingly involved in business activities as board members. At best, the investors can contribute significantly to the businesses of the investee company with their relations and experience. Capital loan financing is measured as money flows from private and governmental venture capital institutions to the biotechnology companies.

In the science-based industry, research collaboration with academic institutions seems to be an essential form of RC. It also reflects the external governmental R&D support intensity. This is because Finnish authorities have typically set a condition of university collaboration for granting their own R&D support to companies. In Stage 2 of regression analysis, we choose academic collaboration and governmental equity financing and capital loan financing separately as variables measuring RC.

3.2.2. Commercially exploitable IAs. In order to avoid circular argumentation, we exploit present sales as a measure of the company's present ability to exploit its SC and RC. This decision is made following the argumentation of Ahonen (2000) and Hussi and Ahonen (2002). The above thinking predicts that value creation occurs in the interaction between all the three categories of IC and, therefore, present sales cannot be taken as a predictor for RC only.

Present sales are taken as a present measure of how effectively commercially exploitable assets have previously been utilized. To a great extent, the anticipated sales seem to rely on the market potential of the future, and not on present sales and present market share. Almost one third of the sample companies had annual sales of less than 100 thousand euros (see Table 4). The oldest companies had relatively high sales volumes.

Present sales are an estimator to measure the part of the IAs that are already exploited commercially. Among the sample companies, the anticipated sales in the years 2001–2006 were on average expected to grow at an annual rate of about 45%. The anticipated sales are a prime determinant in the valuation of the company. In the next section, anticipated sales will be the dependent variable in the regression analysis and will be explained by the indicators of IC.

3.3. Statistical procedure

A methodological contribution of the present study is the combining of econometric analyses with the knowledge-management approach. Econometric modeling is used as our main tool. Factor analyses are applied as an important analysis method. The factor scores resulting from the factor analyses are fed into regression analyses. The anticipated sales of the companies are explained by these regression models.

Thus, there are two stages in the statistical procedure:

Stage 1: Factor analysis is used to identify the three IC factors and produce factor scores for each company.

Stage 2: Regression analysis is used to explain the companies' anticipated sales in 2006. The IC

Table 4. Description of the present and anticipated sales (in millions of euros).

Statistics	*N*					
Millions of euros	Valid	Missing	Mean	Median	Standard deviation	Sum
Sales in 2001	72	0	1.80	.20	4.96	129.85
Anticipated sales in 2006	70	2	11.73	1.40	31.78	821.12

factors are formed by factor scores produced in Stage 1. The factor scores are used as variables in the regression model. In other words, the output of the factor analysis is used as a predictor that explains the anticipated sales of the sample of biotechnology companies.

First, we try to find the forms of interaction between the three categories of IC. According to the knowledge-management theory, this is important for two reasons. First, the value creation in business activities is connected to the interactions between the three categories of IC. Second, there can be interactions that are not strictly connected to value creation. It is important to separate the latter kind of interaction from those that create value. In statistical terms, the interaction between the three categories of IC is measured as the co-variation of the IC-based variables.

The idea in the first stage is to find the common variation between the variables and form the IC factors discussed above. Because an orthogonal factor analysis method is applied, the factors are uncorrelated with each other, which is an advantage in regression analysis. This lowers the risk of multicollinearity between the independent variables. Factor scores are constructed from the factors and they are used as new variables in Stage 2.

Our attempt is to explain the anticipated sales of the companies based on the knowledge-management approach. Regression analysis is used to produce three alternative models. Firstly, we use original variables without the results of the factor analysis. Secondly, we construct a regression model with all the factors received from Stage 1. Thirdly, we regress only statistically significant factors and add some significant dummy variables found in the data.

Despite the fact that we employ cross-sectional data, the analysis is dynamic in a sense similar to Bounfour (2002). We are interested in the valuation of assets and the input–output relations of IC.

4. Results

4.1. Factor analysis

Factor analysis produced four factors in Stage 1. Applying the generalized least squares (GLS) method, the factors interconnected the variables within the three IC components mentioned above (see e.g. Sharma, 1996). We took natural logarithms from other than ratio variables or dummy variables. The communalities for each variable show that the factor model explains 28–78% of the variance of a single variable. The model can explain 73% of the total variance of all the initial variables according to the eigenvalues.

Then, using the rotated factor solutions presented in Table 5, we produced factor scores for each case company and factor by multiplying the factor loadings by the values of the initial variables. Factor rotation was chosen instead of initial factor solution because of the clarity of interpretation of the factors. The factor rotation was carried out using the Varimax method, which is a rotation method that minimizes the number of variables that have high loadings on each factor. Thus, in order to simplify the interpretation of the factors, we utilize the results of the rotated solution.

One factor indicates how different categories of IC interact, or co-vary with each other. For example, the loadings of Factor 1 in Table 5 presents co-variation between the three categories: critical mass of personnel (HC), large patent portfolio, and R&D expenditures (SC), and university collaboration and equity financing from private venture capital companies (RC). Table 5 implies also that Factor 1 is positively related to the pharmaceutical industry and negatively with the service sector.

4.2. Regression analysis

The outcome generated by the IAs is the anticipated future sales in Figure 4 instead of the long-run productivity of capital in Figure 3. The anticipated sales approximate the productivity of capital and the present value of the company because of the following reasoning. The biotechnology industry resembles the pharmaceutical industry in the sense that both have extremely long product-development processes. Consequently, as many as one-third of the companies in the sample are involved in the development of pharmaceutical products. Furthermore, when Scherer and Ross (1990) and Linnosmaa et al. (2004) analyzed price–cost margins in the pharmaceutical industries in the USA and Finland, they found relatively high price–cost margins in both countries. This implies that physical capital does not play a focal role in the value creation process of the pharmaceutical industry. If this is also typical for the biotechnology industry, it seems reasonable to assume that the anticipated future sales imply a growth in productivity of capital and the present value of the company.

Table 5. Rotated factor matrix.

	Factor								
	1	2	3	4	5	6	7	8	9
Patents and patent applications (log)	**0.813**	0.137	−0.014	−0.094	−0.087	0.161	0.002	0.007	0.117
R&D expenditures (log)	**0.810**	0.125	0.159	**0.298**	0.064	0.059	0.082	0.092	0.011
Expenditures on university collaboration (log)	**0.764**	0.148	−0.162	0.153	0.083	0.217	0.050	0.115	−0.109
Personnel (log)	**0.704**	0.159	**0.441**	0.244	0.050	0.028	−0.051	−0.088	−0.020
Services (=1)	**−0.357**	0.020	0.132	0.237	0.275	−0.018	0.165	0.166	−0.047
Pharma (=1)	**0.327**	0.162	−0.107	**0.299**	0.067	−0.112	−0.028	−0.121	−0.038
Equity financing from government VC (log)	0.200	**0.779**	−0.050	0.155	0.055	−0.171	0.139	0.270	−0.086
Equity financing from private VC (log)	**0.307**	**0.754**	−0.045	0.099	−0.134	0.054	−0.011	−0.054	−0.130
Equity financing from persons active in business (log)	−0.015	**0.609**	−0.117	0.091	0.032	0.185	−0.106	0.010	0.065
Industrial enzymes (=1)	−0.104	−0.164	0.058	−0.022	0.045	−0.121	−0.092	0.039	0.094
Present sales (log)	0.102	−0.092	**0.975**	0.000	0.007	0.160	0.030	−0.050	−0.007
Anticipated change in exports per turnover	0.249	0.245	**−0.499**	0.061	0.223	−0.198	0.116	0.203	0.028
Equity financing from other companies (log)	0.395	−0.174	**0.422**	−0.161	0.133	0.021	0.018	−0.158	−0.152
Doctors and licentiates (log)	0.357	0.273	−0.033	**0.888**	0.023	−0.016	−0.027	0.040	−0.063
Agriculture (=1)	0.173	−0.137	0.167	−0.206	0.151	0.019	−0.081	−0.120	−0.063
Diagnostics	−0.034	0.031	0.029	−0.023	**−0.993**	0.008	−0.023	0.078	−0.052
CEO experience (log years)	0.313	−0.002	0.156	0.061	0.043	**0.779**	0.070	0.026	0.150
Age of company (log years)	0.055	0.101	**0.376**	−0.237	−0.190	**0.526**	−0.152	−0.175	−0.004
Biomaterials (=1)	0.167	−0.084	0.065	−0.145	0.150	0.287	0.188	0.049	−0.118
Capital loan financing from private VC (log)	0.011	−0.003	0.008	−0.011	0.007	0.000	**0.999**	0.034	−0.002
Capital loan financing from government VC (log)	0.122	0.155	−0.182	0.002	0.211	0.184	**0.350**	0.064	−0.011
Turku (=1)	0.069	0.121	−0.142	0.017	−0.081	−0.014	0.045	**0.939**	−0.261
Helsinki (=1)	0.000	−0.088	−0.048	−0.059	0.043	0.121	−0.003	−0.238	**0.955**
Problems in skilled labor supply (=1)	0.145	−0.114	0.043	0.259	0.067	−0.215	−0.027	−0.063	0.282

Factor loadings $\geq$ 0.30 bolded.Extraction Method: Generalized Least Squares. Rotation Method: Varimax with Kaiser Normalization.A Rotation converged in seven iterations.B Only cases for which SME biotech firm = 1 are used in the analysis phase.R&D, research and development; VC, venture capital.

Hence, the original theoretical framework by Hussi and Ahonen (2002) holds for the framework in Figure 4.

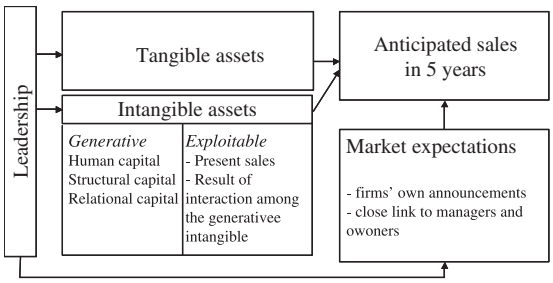

Figure 4. Intellectual assets and anticipated future sales of the company. Modified from Hussi (2001).

The regression analysis exploits the theoretical models presented above. First, we utilize the initial variables without factor scores in the regression analysis. The results of the initial variable models are shown in Table 6. Generally speaking, the initial R^2 ratios show that model 3 explains most of the variance of the variables in the model. However, when the adjusted R^2 is observed, Model 2 holds the best fit.[3] In this setting, the anticipated sales are almost entirely explained by the present sales. This describes size effect (or scale economies) of the companies. To put it simply, if you are big now, you will be expected to be big in the future.

When we regress the anticipated sales, explaining the sales in 2006 by the initial variables, only

Table 6. Regression model: explaining anticipated future sales of small- and medium-sized biotechnology companies by initial variables.

Dependent variable: anticipated sales in 2006			
Variable Logarithmized variable (log) Dummy variable (*d*)	Model 1: without dummies	Model 2: extended model	Model 3: extended model with tangible assets
R^2	0.744	0.817	0.837
Adjusted R^2	0.672	0.705	0.691
F-test	10.384***	7.267***	5.732***
Constant	**1.880** (0.909)**	1.666 (1.070)	1.112 (1.644)
Present commercially exploitable assets			
Present sales (log)	**0.914*** (0.126)**	**0.956*** (0.144)**	**0.912*** (0.183)**
Human capital			
Personnel (log)	−0.131 (0.291)	−0.477 (0.313)	**−0.684* (0.385)**
Doctors and licentiates (log)	−0.174 (0.343)	−0.529 (0.391)	−0.367 (0.546)
CEO experience (log)	−0.019 (0.330)	0.070 (0.401)	−0.697 (0.566)
Structural capital			
R&D expenditures (log)	0.156 (0.154)	0.230 (0.160)	0.284 (0.193)
Patents and patent applications (log)	−0.037 (0.215)	−0.121 (0.256)	0.160 (0.331)
Age of company (log)	−0.368 (0.371)	−0.397 (0.396)	0.152 (0.672)
Relational capital			
Equity financing from other companies (log)	0.066 (0.081)	−0.089 (0.088)	0.122 (0.104)
Equity financing from persons active in business (log)	0.123 (0.087)	−132 (0.091)	**0.222* (0.114)**
Equity financing from private VC (log)	−0.130 (0.105)	**−0.200* (0.118)**	−0.202 (0.135)
Equity financing from government VC (log)	0.092 (0.098)	**0.282** (0.118)**	0.185 (0.168)
Capital loan financing from private VC (log)	0.151 (0.108)	0.029 (0.090)	0.058 (0.162)
Capital loan financing from government VC (log)	0.004 (0.087)	0.055 (0.114)	0.123 (0.119)
Expenditures on university collaboration (log)	0.047 (0.132)	0.136 (0.143)	−0.039 (0.184)
Anticipated change in exports intensity (% units)		0.002 (0.812)	−0.419 (1.063)
Problems in employing skilled labor (*d*)		**1.136** (0.519)**	0.797 (0.613)
Pharmaceuticals (*d*)		0.217 (0.471)	−0.153 (0.550)
Diagnostics (*d*)		0.566 (0.544)	0.287 (0.721)
Biomaterials (*d*)		0.667 (0.553)	0.884 (0.646)
Industrial enzymes (*d*)		−0.592 (0.843)	0.203 (1.260)
Agriculture (*d*)		0.152 (0.959)	−0.171 (1.122)
Services (*d*)		0.569 (0.595)	−0.129 (0.755)
Helsinki (*d*)		−0.064 (0.570)	0.058 (0.657)
Turku (*d*)		**−1.211* (0.632)**	−0.746 (0.872)
Tangible assets (log)			0.108 (0.177)

Standard errors are in parentheses. The asterisk labels (*) stand for the level of the statistical risk of denying incorrectly the null hypothesis: the regression coefficient is zero.*10% risk level.**5% risk level.***1% risk level.R&D, research and development; VC, venture capital. Statistically significant coefficients shown in bold.

Table 7. Regression model: explaining anticipated future sales of small- and medium-sized biotechnology companies by interacting factor scores.

Dependent variable: anticipated sales in 2006			
Variable	Model 4: all the factors	Model 5: focal factors	Model 6: focal factors and tangible assets
R^2	0.724	0.703	0.722
Adjusted R^2	0.678	0.688	0.700
F-test	**15.736*** **	**47.273*** **	**31.869*** **
Constant	**7.001*** (0.180)**	**7.009*** (0.177)**	**5.800*** (1.313)**
Factor 1: HC + SC + RC + pharmaceutical non-service sector	**0.461** (0.192)**	**0.468** (0.188)**	0.297 (0.270)
Factor 2: RC	−0.100 (0.195)		
Factor 3: HC + SC + RC + commercial exploitability	**2.137*** (0.193)**	**2.125*** (0.188)**	**2.029*** (0.260)**
Factor 4: HC + SC + pharmaceutical sector	0.010 (0.185)		
Factor 5: non-diagnostics sector	0.194 (0.183)		
Factor 6: HC + SC	0.135 (0.214)		
Factor 7: RC	**0.461** (0.178)**	**0.458** (0.175)**	**0.371* (0.198)**
Factor 8: Location in Turku	−0.217 (0.181)		
Factor 9: Location in Helsinki	0.155 (0.182)		
Tangible assets			0.100 (0.118)

Standard errors are in parentheses. The asterisk labels (*) stand for the level of the statistical risk of denying incorrectly the null hypothesis: the regression coefficient is zero.*10% risk level.**5% risk level.***1% risk level.HC, human capital; SC, structural capital; RC, relational capital. Statistically significant coefficients shown in bold.

few of the variables are statistically significant. The model does not contain the interaction effects of IC trying to relate IC measures directly and separately to value creation (anticipated sales).

Next, we conduct the second phase by employing the factor scores formed above in the factor analysis. These factors describe how the three forms of IC are interlinked. The results of the factor-based models 4, 5, and 6 are presented in Table 7.

In Model 4, we employ all the factors received from the GLS method factor analysis in Stage 1. It implies that Factors 2, 4, 5, 6, 8, and 9 do not significantly explain the anticipated sales. Therefore, we drop these factors from Model 5. Then we add IAs to the analysis in Model 6.

Models 4, 5, and 6 are able to explain about 70% of the regressors' variance. For example, according to the adjusted R^2, the independent variables in Model 6 are able to predict systematically 70% of the variation of anticipated sales.

The successful predictors are the chosen IC factors. As a result, the company anticipates high sales if the company's IC is well balanced according to Factors 1 and 3 in Models 4 and 5. Factor 1 deviates also significantly from zero in Models 4 and 5, but remains insignificant in Model 6. Model 6 contains a severe problem of multicollinearity: the independent variables Factor 1 and tangible assets correlate significantly ($r = 0.439$, $P = 0.001$). This indicates that research-intensive activities require also significant investments in equipment and other tangible assets. Technically, because of the multicollinearity, Model 6 loses one dimension and Model 5 can be held more depictive (see also the sensitivity analysis in Section 4.3). Factor 7 links capital loan financing (RC) with the anticipated future sales in Models 4, 5, and 6. In the next section, results of the empirical analysis are discussed.

4.3. Discussion on empirical analysis results

Factor analysis measured interaction through statistical correlation (loadings) between initial variables and new factors obtained in the analysis. The loadings of these factors implied how different categories of IC correlate with a single factor. Then factor scores were used in creation of new variables for each factor in the final solution. This formed the basis for measurement of interaction between the three categories of IC. In other words, high scores within some factor implied that the company has a high (low) amount of all these forms of IC that have high (low) loadings to this specific factor, respectively.

The IC-driven value creation of Factor 1 is depicted in Figure 5. There is the following covariation within the three IC categories explaining high anticipated sales. A critical mass of person-

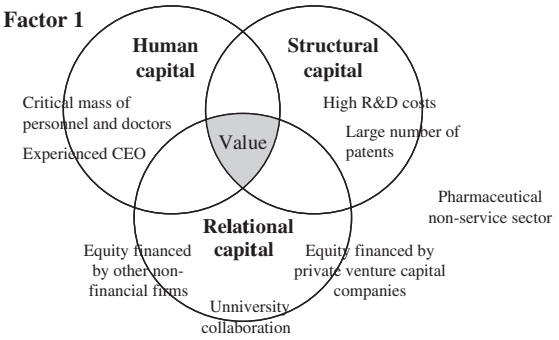

Figure 5. Intellectual capital- (IC-) driven value creation within the small- and medium-sized biotechnology companies (Factor 1).

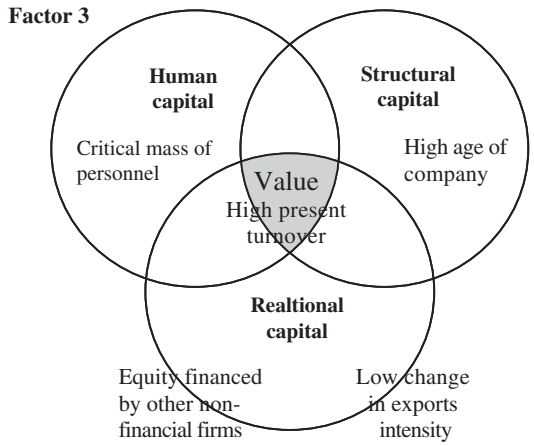

Figure 6. Intellectual capital- (IC-) driven value creation within the small- and medium-sized biotechnology companies (Factor 3).

nel and doctors is directed to R&D activities, which are supported by a large patent portfolio. These companies are financed by private venture capital companies and other companies. The most promising companies, within Factor 1, are partially related to the pharmaceutical sector.

In other words, Factor 1 implies, that if the biopharmaceutical company holds a critical mass of personnel and an experienced CEO (HC), high R&D costs, and a large patent portfolio (SC), and it has intensive collaboration with universities and it is equity financed by other firms and private capital companies (RC), the company achieves high factor scores of Factor 1. The regression analysis models how these IC factor scores are linked with the anticipated future sales of the companies. The model results indicate that a high (low) Factor 1 score predicts high (low) anticipated sales in 2006, respectively.

The same logic applies to Factor 3. The critical mass of personnel (HC), high age of the company (SC), and significant equity financing from other firms together with a low change of anticipated export intensity (RC) predict a high volume of anticipated future sales in 2006 (Figure 6).

Factor 1 emphasizes the significance of holding a patent portfolio in the drug development business. Patents and patent applications form a necessary base of intellectual property rights for commercial exploitation. It is critical to hold patents related to those molecules which are the basis of the company's own drug development. Without patent protection, any other company can develop a generic drug based on the same chemical compound as a treatment for some specific disease. Without patent protection, another company can free ride and get the same drug into the market through passing the generic drug-approval process. In such a case, the free-rider company can accomplish this with a very limited amount of R&D expenditures compared with the companies, which invent new potential drugs.

Factors 1 and 3 present how the Saint-Onge's et al. value platform is concretized within the Finnish biotechnology industry (Figure 6). These companies have an above-normal present sales level as was not the case in Factor 3. Factor analysis seemed to be able to divide the size effect more effectively than the first regression model with the initial variables. For example, Factor 3 is closely related to present sales and the critical mass of personnel in Models 4, 5, and 6 as initial separate variables are in Models 1, 2, and 3, too. In contrast, Factor 1 is not loaded with present sales level at all, but R&D activities, number of patents, or university collaboration.

In this empirical setting, Factor 7 implies that capital loan financing from both private and governmental sources is strictly connected to the anticipated sales volumes of the biotechnology companies. However, the sensitivity of the solution of Factor 7 should be investigated, because the results of the factors, which explain a minor part of the variance of the initial variables, can be sensitive to the method used. However, the link between capital loan financing and anticipated sales remains interesting. Factor 7 may refer to the dynamic impacts of financing. For instance, it would be important to investigate to what extent a company, when approaching potential financiers, raises its own estimates of anticipated future sales in order to get capital loan financing, and to what extent the company's capabilities to exploit the market potential are strengthened as a result of being successful in raising new financing.

4.4. Sensitivity analyses

In order to test how sensitive the results presented above are in relation to the compressing method, we employ the principal component analysis (PCA) instead of the GLS method factors. Then we apply the principal component scores in regressing the IC interactions towards the anticipated sales of the biotechnology companies. The results remain mainly parallel in the PCA. The R^2 of the regression model applying the PCA is 61.4%, which is somewhat lower than in the analysis applying the factor analysis. Four significant principal components were found instead of the three (or two) factors explaining the anticipated sales.

The PCA comprises qualitatively similar basic features as the factor analysis. For example, in the PCA, components related to Factors 1 and 3 could be identified. The variables related to the region of the companies do not seem to be robust in this benchmark model. The Helsinki region with business experienced leaders and capital loans from government institutions explain part of the anticipated sales in the benchmark model. Part of the anticipated future sales is explained by service companies that are already generating some sales and are owned by individuals active in business.

Another sensitivity analysis was made by performing the same research analyses using relative measures instead of absolute measures. The relative measures were attained from the absolute measures by dividing each of the values of the original variables by an appropriate variable representing the size of the corresponding company. Obviously, this transformation was not needed for dummy variables or variables which already are ratios. Appropriate variables for dividing the values of original variables were, for example, total costs or number of personnel of the company.

In the GLS factor analysis carried out with the relative measures, three factors significantly explained the anticipated sales. The R^2 of the regression model utilizing relative measures is 29.8%. The first factor had positive loadings with the variable describing other companies' relative equity share and with the company's innovation intensity, which was measured by the ratio of patents and patent applications to labor involved in R&D activities. The first factor had a negative loading with the relative equity share of individuals active in business. The second factor had a positive loading with the ratio of present sales to labor, with the logarithmized age of the company and the ratio of government venture capitalists' equity to total equity. The third factor had a high loading with the ratio of present sales to labor. Factors 1, 2, and 3 were related to the branches of agriculture, service, and diagnostics, respectively.

The factor analysis applying the relative measures was not able to reveal the detailed structures behind the anticipated sales. This analysis stressed the importance of present sales per labor and of branch-specific features. These results, together with the results of the PCA above, raise a need for a closer look at branch-specific phenomena within the biotechnology industry.

5. Conclusions

The present study relates the knowledge-management theory and the measurement of IC (intellectual capital) to the anticipated sales that small- and medium-sized biotechnology companies have articulated. According to the literature, value is created by the interaction of the three categories of IC, namely HC, SC, and RC (human, structural and relational capital).

We tested the theoretical framework among small- and medium-sized Finnish biotechnology companies. In the first stage of empirical analyses, we identified factors that present interaction between the variables measuring the different categories of IC.

In Stage 2 of the empirical analysis, we constructed two kinds of regression models that explained the anticipated sales of the companies. Firstly, we utilized the initial variables. Secondly, we exploited factor scores from Stage 1. The regression models implied that the strict effects of single initial variables without interaction explained the anticipated sales at a general level as much as the factor-based variables that take into consideration the interaction between the categories of IC. The initial variable model stressed the present ability of commercialization as an explanation for anticipated future sales.

The factor-based model seemed to be able to separate some size–effect features. Particularly, two IC-related factors were found that systematically explain the anticipated future sales. Both these factors link to some degree HC, SC, and RC. According to the first factor, the companies with the highest anticipated sales levels have the critical mass of highly educated personnel and doctors directed to R&D activities. These com-

panies hold a large patent portfolio and they are partially owned by private venture capital companies and by other companies. According to the second factor, the critical mass of labor of an aged company has already generated sales. The company is mainly owned by other companies. The third significant factor is related to capital loans offered by private and governmental venture capital companies.

Three paths for further research are evoked by the present study. Firstly, in the present study, some preliminary results concerning explanations for the anticipated future sales of Finnish biotechnology companies were obtained. Deeper analyses could help to build various economic forecast models. These could be, for example, macroeconomic, industry-specific or region-based. Secondly, a follow-up study of the same sample of companies would be very attractive. In it the real sales of 2006 could be compared with the anticipated sales, which was articulated by the company managers in 2002. What kind of companies were the most successful in realizing their anticipated sales? Thirdly, it would be interesting to investigate to what degree various kinds of investors have been able to select the companies that have turned out to be the most successful in terms of economic profitability and in terms of continuous IC development.

To conclude, the theory-based tool developed in the present study can be utilized in the valuation of knowledge-intensive companies with high growth prospects but long and insecure product development phases. The tool was able to relate the present and measurable stock of IC with the highly insecure anticipated future sales projections, which are conventionally held as direct sources for the estimation of the present values of companies. Accordingly, this systemic tool could serve as a basis for the valuation of companies within science-based and knowledge-intensive sectors, such as biotechnology, displaying high growth anticipations and business risk.

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Notes

1. The paper draws on the ETLA and Etlatieto Ltd survey of Finnish biotechnology companies, conducted in March–May 2002. Descriptive survey findings have been reported in Hermans and Luukkonen (2002a) and Hermans and Tahvanainen (2002b).
2. Nonaka and Takeuchi (1995) define their seminal model in which they interpret how the tacit knowledge is converted to explicit knowledge and back to the tacit knowledge of other individuals and groups. In the present study, we do not focus on the so-called SECI (socialization-externalization combination-internalization) model but instead we focus on measuring the interactions between different categories of intellectual capital and its impact to anticipated sales.
3. Conventional R^2 increases with the variables included in the model and decreases with the number of cases included in the analysis. The adjusted R^2 takes those matters into account.

Appendix 7. Variability of Organisational Forms of Biotechnology Firms

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Variability in organisational forms of biotechnology firms☆

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Abstract

This paper examines the variability of organisational forms in terms of forward and backward networking versus vertical integration in biotechnology SMEs. The study examines forms of organisation in a set of firms across application segments. The forms of organisation vary by application segment in biotechnology, but differences are not clear-cut, and a firm can apply different forms to different application segments in its activities. The reasons for this variability are related to the stringency of the regulatory approval systems, technological risks, and the costs of building full-scale manufacturing facilities which influence funding needs and thus also the choice of organisational form. The paper finally discusses the notion of networking as a separate form of organisation of economic activity and the extent of its applicability to biotechnology.

Keywords: Organisational forms; Biotechnology firms; Network company

1. Introduction

In the field of biotechnology, alliances and networks are essential and appear to be a key factor for the survival and growth of new biotechnology firms (e.g., Powell et al., 1999; Niosi, 2003). Established firms invest in biotechnology R&D in specialist small firms through R&D contracts, equity investments and joint ventures (Powell, 1990; Sharp and Senker, 1999). In exchange for their support, they obtain exclusive or shared rights to specific technologies or products that emerge from the new biotechnology firms' R&D programmes. The latter obtain funding for R&D, and both funding and expertise for manufacturing and marketing their products. These arrangements have been so frequent and intensive that they have even been regarded as a new organisational form (a network company as contrasted with markets and hierarchies; see Powell, 1990; Powell et al., 1996; Mangematin et al., 2003), or as a hybrid governance form (Williamson, 1991).

Nonetheless, Pisano (1991) noted a reverse trend towards forward vertical integration by new biotechnology firms into manufacturing and marketing, and backward integration by established firms into

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biotechnology R&D (see also Senker and Sharp, 1997). According to Pisano, at the same time, organisational structures to source or commercialise technology have become more diverse and hybrid.

A lot of previous research in biotechnology has concentrated on pharmaceuticals-related biotechnology, which is the earliest and probably still the most typical application sector of new biotechnology. However, even in pharmaceuticals-related application areas, the business and networking strategies of biotechnology firms may differ. One may presume that this applies even more to other biotechnology application areas. Further, much of the research on biotechnology firms has been carried out in the USA, where biotechnology was commercialised earlier than in Europe. US circumstances differ from those in small European countries, not only because the biotechnology business sector is more mature there, but also because there are large established firms in the various application areas of biotechnology with resources for networking with small biotechnology firms. Moreover, the private venture funding sector is well developed in the US, offering both alternative and complementary sources of funding for the new biotechnology firms. In a globalised world, access to partners and funding, either locally or nationally, most probably is not a necessary condition for biotechnology firms to function. However, it is likely to be a facilitating framework condition.

This paper examines the extent to which networking and vertical integration in new biotechnology firms differs in different application areas and compares firms in and outside the pharmaceuticals sector. The viewpoint of the paper is that of a new firm. The paper focuses on the factors that influence the observed diversity. The empirical research material comes from a small European country where new biotechnology firms are a much more recent phenomenon than in the USA, giving rise to more varied circumstances under which these firms hope to survive and grow. Private venture funding is also scarcer. Further, the paper will discuss the notion of networking as a form of governance and its applicability to biotechnology.

Finally, the question of organisational form adopted by new biotechnology firms is of policy relevance. Different organisational forms can influence the growth prospects of biotechnology firms and the potential returns to investments in R&D, which in many countries are heavily dependent on public money. This is the case in, e.g., Finland where, since the late 1980s, research funding agencies have invested large sums of public money in biotechnology R&D, motivated by great expectations concerning a new growth sector. Whether these expectations are realistic will be touched upon at the end of this paper.

2. Networking and forms of organisation

There exist a host of studies on networking or alliances in biotechnology (e.g., Pisano, 1991; Liebeskind et al., 1996; Audretsch and Stephan, 1996; Zucker and Darby, 1996; Niosi, 2003; Mangematin et al., 2003;). Being strongly science-based, biotechnology firms have emerged as research spin-offs from academic or established industrial firms. Entrepreneurs in the new biotechnology firms often come from universities, and the firms are located near academic institutions, with which they collaborate intensively (e.g., Zucker et al., 1998a, 1998b; Stephan et al., 2000). Further, new firms lack funding for R&D that is needed for developing their inventions into products or processes. They lack resources and capabilities in manufacturing, clinical testing, regulatory processes and distribution/marketing, while incumbent firms can offer these capabilities (Powell et al., 1996; Pisano, 1991; Senker and Sharp, 1997). In Teece's terms (1986), it is a question of large and small firms having complementary assets. The established firms lack competencies in biotechnology R&D, a lot of which is tacit, and which in the earliest phase of the development of the field (in the 1970s and the 1980s, in particular), was centred in a few places (Zucker et al., 1998a; Sharp and Senker, 1999). Small firms are also regarded as more flexible, that is, able to react to new challenges and more innovative in new areas. Technological uncertainty has, further, played a role in the established firms' decisions to contract out for R&D in biotechnology (Sharp, 1985; Pisano, 1991). These observations have led to the notion of small biotechnology firms being exemplars of network firms.

This picture has recently been further elaborated by, e.g., Mangematin et al. (2003) who, drawing on data from French biotechnology firms, noted that the frequency of alliances among biotechnology firms is related to business models. They classified all new biotechnology firms, SMEs, into two classes. The first

group comprises companies which have large research programmes aiming at broader markets and have high expectations of future growth and profits. The authors show that these companies typically enter into contracts with big industrial groups. In a study of Canadian firms, Niosi (2003) noted that this business strategy is more often characteristic of a firm aiming at human health products. The second group, according to Mangematin et al. (2003), are biotechnology SMEs which run small projects, target small and segmented markets, often domestic, and make incremental innovations, manufacturing their own products and marketing them. In the latter case, the need for alliances with bigger companies is limited, and the organisational structure is typically that of a vertically integrated firm.

In addition to business models, intellectual property rights systems have been noted to be important for networking and alliances (Teece, 1986; Arora and Gam bardella, 1994). A division of intellectual labour—and thus co-operation within a network—relies on strong intellectual property rights. A clear division of intellectual labour between small and large firms can be observed in the pharmaceutical industry, where patent protection is more effective than in other sectors (Levin et al., 1987). Another reason explaining strong property rights is the fact that the knowledge base can be articulated in universal categories, thus facilitating the codification of knowledge in patenting (Arora and Gam bardella, 1994). Also Teece (1986) has noted that, in addition to the efficacy of legal mechanisms of protection, the nature of technology (product versus process and tacit versus codified) is an important dimension for appropriability and related to vertical integration versus disintegration. With effective property rights protection, codified knowledge and product innovation firms are more likely to be vertically disintegrated.

It thus emerges from previous research that there is variation in the extent of forward collaboration versus vertical integration in new biotechnology SMEs. This is related to the business models of the firms, and probably to the application segment of biotechnology with human health and pharmaceuticals firms being more inclined towards alliances and collaborative arrangements. However, Mangematin et al. (2003) argue that firms in the same application segment may choose different strategies.

Further, the intellectual property rights systems are related to the extent of networking and alliances, creating the conditions under which a system with extensive division of labour and alliances can evolve. It can be presumed that extensive division of labour further reinforces the intellectual property rights protection and induces firms to patent.

Networking, alliances and co-operation have been used interchangeably in the above analysis, as is the case in many studies on biotechnology. Different types of co-operative relations, such as those based fully on informal agreements versus those based on formal contracts, differ in their nature and function. The final sections of this paper will pay attention to this distinction and will discuss the concept of a network company and some of the assumptions underlying it.

2.1. Research questions

The paper assumes that instead of two distinct business strategies or models, as defined by Mangematin et al. (2003), there is more variability among biotechnology firms. Particular attention is paid here to forms of organisation, which means the reliance of the small biotechnology firm on vertical integration versus networking in its research, product development, product approval, manufacturing, and marketing activities. The term forward networking here means collaborative solutions with other companies in manufacturing and/or marketing while backward networking means collaboration with a university or a research institute in R&D.

This paper examines reasons for the observed variability in forward networking versus vertical integration. It is assumed first that networking solutions are typically used in human health products, while in other segments their prevalence varies. This study aims to test this assumption and to understand the rationale for variation. As the above references imply, one of the factors potentially influencing the decision concerns a need for and access to resources, especially money. Large companies which biotechnology SMEs make R&D contracts with or license their IPRs out to provide an important source of funding needed for the R&D processes of the SMEs. Alternative or additional sources are provided by public or private venture funding organisations, or, in the case of very early research stages, public R&D funding organisations. According to Lerner and Merges (1998), in pharmaceuticals, however, alliances with large firms have become the single largest source of financing for biotechnology firms.

concerned the number of innovative products in the pipeline and/or the stages at which they intended to or already out-licensed their products. According to these firms, the best insurance against risks was to have several inventions/products at different stages when out-licensed, thus securing a mix of resources in the short and long term. However, this was not always possible for reasons related to access to funding. Thus, the business of out-licensing product innovations is based on a highly developed division of labour among various firms and networking.

All the drug discovery firms had had access to some venture funding, private or public, national, regional or foreign, and some had had a few funding rounds. Nevertheless, this was seldom sufficient for the envisaged development process. The sums secured were in most cases relatively small. Even an initial public offering does not necessarily secure a great deal of funding, particularly not in a small market such as Finland. Further, the public financing window has been closed because of the downturn in the capital market since 2001. The need for funding is currently regarded by the CEOs as the most acute problem of the sector in Finland. This need was an important factor determining the stage at which products were out-licensed—and thus for the present and future revenues of the firms.

It is to be noted that the present forms of organisation in terms of forward collaboration/networking have not necessarily stayed unchanged (cf. Mangematin et al., 2003). Some firms had started with expectations—which proved to be unrealistic—that they might be able to obtain the resources to build large-scale manufacturing facilities. The networking strategy has, in some cases, been the result of a painful learning process. Obtaining a competent—mostly foreign—venture funding organisation as an investor in the beginning helped some of the firms to build a viable business strategy at the outset. Even though all firms had obtained some venture funding, most had not been as fortunate—or rather had not had the networks to obtain such funding and/or had not had equally attractive inventions to offer.

4.1.2. Diagnostic firms

Diagnostics is also related to pharmaceuticals through pharmaceutical therapy and diagnosis. Firms may produce ingredients of monoclonal antibodies such as purified protein or antigens, or further, they may produce tests or markers that are key components of tests. Some of the firms produce these for therapeutic use, some also for research, not just for medical therapy or industrial uses. Firms are also involved in producing biosensors for, e.g., environmental monitoring R&D activities. The business logic of the firms engaged in diagnostics by and large differs from that in drug discovery firms, with no major differences in the strategies of firms across different diagnostic segments.

The diagnostic firms in the interviewed dataset were engaged in developing, manufacturing and marketing raw materials, such as antibodies or reagents for diagnostic tests, or the tests themselves. A major part of their customers are foreign companies. Some firms used distributors in their specific market segment. Two of the firms provided or had provided services in the early phase of their activities since these offer a quick cash flow. All the firms were vertically integrated firms, though one of the firms resorted to a partial network solution by subcontracting some of its manufacturing activity.

In diagnostics, there is no regulatory approval system and it is possible for firms to introduce new products as soon as they have developed them and set up systems to make them. A young firm may obtain revenues from the start and is far less in a need of external funding. Only two of the five firms had obtained venture funding, national, regional or public; one as capital to start the firm, and the other to develop new products, yet in the former case, the sums were very small. Overall, the required funding to start and develop business is much smaller than in drug discovery.

All the firms had patented their processes or test techniques. In diagnostics, however, not everything is being patented. Specific tests (test kits) are typically patented, but antibodies which are used as a raw material for making tests are not. Since these firms typically are engaged in producing both, they have patented only some of the knowhow related to their innovations. These companies often also used trademarks to protect their intellectual property. It is also true that many of the basic methods used in diagnostics, such as the methods to make monoclonal antibodies, are based on discoveries originally published as scientific discoveries and not patented (in the 1970s). This happened at a time when patenting was not practiced as widely as today. The competitive advantage for the firm is its tacit knowledge concerning the practical working methods of, e.g.,

how to extract antibodies and markers most effectively and with the intended impact. Even though firms may in principle be aware of the basic methods, their ability to make the end product varies. Firms may be able to license out their products, such as cell lines, without having patented them, facilitated by having mastered the technique effectively.

4.1.3. Biomaterials

Biomaterials are also used in the health care sector. Biomaterials are used in, e.g., orthopedic dental and cranio-maxillofacial applications or other solutions for musculoskeletal reconstruction and temporary stenting (implants). Biomaterials often replace older materials, such as metal plates, used in surgery. New and developing application areas are, for example, drug delivery and tissue engineering.

In terms of networking versus vertical integration, biomaterials is between drug discovery and diagnostics: four out of the five biomaterials firms aim at product innovations and out-licensing the IPRs. However, the main activity of the four firms is to manufacture their products, and in three of the five firms, also to market them.

Some biomaterials firms use distributors in the specific segment. This has the benefit that these have former customers and existing markets. Often the same distributors offer both conventional and new products (e.g., biomaterials versus metal plates for surgery) to their customers. Especially in the case of niche markets for specific products, professional groups, conferences, fairs, Internet-based advertising, training, and direct marketing to potential customers have been used. Marketing efforts are facilitated by the fact that the customers consist of hospitals and medical personnel. In one company, a foreign parent was in charge of marketing by utilising its worldwide market networks.

One of the firms involved in developing innovations and out-licensing the IPRs is a holding company, founded to commercialise research results of university researchers in the biomaterials field, and is thus not fully comparable to the rest. Another firm, not involved in marketing, is owned by a US firm, which markets the products. One of the firms also intends to do business in manufacturing for other companies under their brand name either using their design or its own design. All except the holding company had received venture funding. One had had an IPO in New York.

In biomaterials, the product approval process is much shorter than that in human drugs, though it depends somewhat on the application. The most stringent requirements concern biomaterials which are used inside the human body as contrasted with outside uses (such as on teeth). The US Federal Drug Administration requires clinical tests, but these do not follow the procedures set for human drugs. In European countries, there is a certification process by specific notified bodies after which the product can be given CE approval and be marketed in the European Union. Many countries outside the EU accept the European certification.

The overall development of biomaterials products from discovery to market launch is shorter and less expensive than in drug discovery, enabling small biotechnology firms to integrate manufacturing. Marketing is also within their reach through the use of existing distributors in medical devices. The markets are for the most part located abroad. One of the firms has a group of test users in various countries. These test the product before the actual market launch and suggest improvements before a major launch. Patenting is important and all firms do so. Patents are usually taken on materials, techniques, and/or work processes.

4.1.4. Services

Since biotechnology is highly networked, it offers many opportunities for service providers. The service firms interviewed were engaged either in consulting or in R&D services. One firm was a vertically integrated firm, since it manufactured diagnostics components for its customer firms. Most of the customers of the service firms were other biotechnology (diagnostics, food) or pharmaceuticals firms. One of the service firms subcontracted special analyses to other R&D service firms. None of the service firms had patented their knowhow, since it was based on publicly available knowledge and on their own acquaintance with processes, though some had plans to patent potential new methods to be developed in the company. New methods development is, however, mainly researched in universities in connection with basic research on, e.g., health issues and the diagnostics of various diseases. New methods development information is normally published in connection with the publication of the original discoveries and thus cannot be patented. Marketing is typically part of the everyday business of a service firm and cannot be contracted out. Service

firms differ from other firms in that often their major customers are in Finland, while firms in other types of business mainly cater to foreign customers. However, one R&D service firm in a narrow subject area had the majority of its customers abroad. Local demand for its services is too limited to offer a viable business model.

The special advantage of service firms is their ability to apply specific—yet generally known—methods in an effective way, and also the fact that they have the required instruments and trained personnel at hand. A lot of service provision is based on tacit knowledge. These firms learn to apply the latest techniques and methods through either informal contacts with university staff or by contracting them formally to teach their personnel.

Only two of the firms had obtained some venture funding as founding capital. Service firms accrue income from their services and, despite being young, they do not need large investments to pursue their business activity.

4.1.5. Other

4.1.5.1. Food and feed. The table in Appendix A lists only two companies under biotechnology-related food products. These two both operate in functional food production. A service firm is also in the functional food field. One of the two food firms carries out R&D to make product innovations in the functional food field and its business strategy is to out-license the discoveries. It does, however, take the development up to the production stage and is therefore in need of venture funding to finance the process. The other firm is in a very narrow niche market for functional food, and has created a production organisation and markets its products through a distributor. Both have patented their basic inventions.

In functional food, the approval system varies from country to country. There is no joint European legislation on the matter. The way health-related claims are treated in product approval differs among the European states and between Europe and the USA. It is easy for companies to launch new food products; however, substantiation of health claims may prove much more difficult. This is also a market which has widely different potential demand in different countries, since conceptions concerning food are culturally conditioned and health concerns vary. It is not so much a question of acceptability, as in genetically modified food, but of an interest in and market demand for health food products.

4.1.5.2. Miscellaneous. The last group includes, as the name indicates, a set of firms in many business areas: an instrument manufacturer (in surface chemistry instrumentation for pharmaceutical drug screening, research and environmental monitoring), genetic protein modification and engineering, bioinformatics, and drug delivery. The firms have somewhat different strategies varying from developing innovations (and out-licensing) to full vertical integration of various functions.

The instrumentation firm has a US owner which is in charge of its marketing (a leading provider of drug discovery, genetic screening, and chemical analysis tools and instrumentation). The volume of the specific instrument production is not large and the SME is able to organise it through subcontractors. By contrast, the SME involved in industrial enzymes (genetic protein modification and engineering) is very small (with a staff of only three people) and only involved in developing innovations on a small scale. It has adopted this business strategy knowing that any other strategy would require a major input of venture funding, which it is not in the position to obtain on acceptable conditions. The bioinformatics firm is fully integrated and, in addition to innovation development and marketing, is engaged in services. The development of software and its marketing does not require major financial investments, and therefore an integrated form of organisation is possible.

Finally is the drug delivery firm. Since it does not develop the molecules itself, but the delivery technology, the process of developing innovative products and taking them to market does not take as long as with a drug discovery firm. Still, the products have to be tested clinically. The firm is networked in many ways, i.e., it has a portfolio of ties to specific partners for certain activities (Powell, 1998): with university researchers for more fundamental questions, with a research institute on questions related to measurements and production technology, with a partner firm on medical molecules to be delivered, with a supplier on manufacturing the device, and finally, with a partner firm on marketing. As a part of the strategy, it considers the possibility of licensing out the IPRs for its basic innovation at a later stage.

4.2. Backward networking

Since backward networking, in practice, collaboration with universities, did not differ in different application segments, this question is treated jointly for all segments. With the exception of one firm, all the firms collaborated with universities in R&D. The exception was a consultancy firm for the commercialisation of biotechnology innovations in a particular foreign market, a very specific business idea having a niche market. Again, only two firms relied on informal networking without any formal arrangements. In practice, informal relations mean that the company monitors the developments on the research front through the personal relations of its personnel. One of these two was a one-man consultancy, and in the other university relations were established on the fact that the CEO owner was also a university professor and through the research activities of his colleagues and students was able to survey the developments. Once he found something interesting, he started to develop the ideas into practical applications within the company. As to the rest, the relations were formal, or both formal and informal.

This is in accord with the findings of Liebeskind et al. (1996) that the sourcing of new knowledge in biotechnology firms takes place through social networks. However, once there are research findings that have potential commercial value, the firm makes formal contracts for the further development of the findings into products. Thus, market arrangements are needed to guarantee the intellectual property for the commercial utilisation of the invention. Zucker et al. (1998a) noted that because biotechnology discoveries are characterised by natural excludability, scientists who make these discoveries do not give away the fruits of their intellectual labour to firms, but instead enter into contractual arrangements with them.

According to this study, contracts are typically about patenting and the utilisation of product innovations. Product development is most often done in the company. Usually, the ownership of the utilisation of the invention is transferred to the company. The latter pays the patenting fees and makes an agreement with university researchers on the division of potential future royalties, sometimes also paying a fee immediately. Another form of formal collaboration consists of contracting out specific studies or analyses to university institutes. In some cases, a company has a network of researchers who have agreed to offer their inventions with commercial potential to the company for commercialisation. These networks are informal, though they may also consist of the group of researchers who were actively engaged in establishing the firm. In all cases, the companies seek to secure the IPRs to the inventions (either through ownership or exclusive licensing rights) which they wish to develop further into commercial products.

There are also networks of university researchers with a formal function as members of an Advisory Board/Medical Advisory Board of the company. They provide input to the research programme of the firm and help organise user trials or clinical testing of products. Being senior scientists, these members can influence purchasing policies in their home institutions and thus can be helpful in the eventual marketing of the end product. The Boards typically consist of both Finnish and foreign members. Alongside scientific publications and patenting, Advisory Boards are of significance in signalling to venture funding companies the potential (scientific) value of the company and its products.

Several companies had obtained R&D funding from the National Technology Agency (Tekes) at some point in the past. Tekes does not provide risk funding like Sitra, a public venture fund, mentioned in the table in Appendix A. Tekes provides two types of R&D funding: direct support or offers loans to the company for its development projects or funding for company–university collaborative projects. It does not assume equity in firms even though it may offer equity loans to young firms. Company–university collaborative projects are typically coordinated by university (research institute) researchers, and provide companies with an opportunity to "peek" at the research front. Because of the public funding, these consortia have formal contracts and provide some of the formal relationships which appear in the table in Appendix A.

5. Factors affecting the organisational form

5.1. Forward collaboration versus vertical integration

In accord with Pisano (1991), the organisational structures in small biotechnology firms have become diverse and hybrid. Many forms of organisation co-exist in small biotechnology firms (cf. Mangematin

et al., 2003). These forms seem to be related to the application segments of the firms. In drug discovery, the forms of organisation were mostly based on network solutions, i.e., alliances with large pharmaceutical firms which develop the new products further. In the other application segments, the degrees of networking versus vertical integration varied, though firms in diagnostics, biomaterials, and services were largely vertically integrated. Several firms used partly integrated, partly network solutions.

The study pointed to co-variance between the regulatory approval systems in the application segment, the effectiveness of the property rights protection regimes, and form of organisation or strategy of a small biotechnology firm. The strictness of the regulatory system influences the overall costs of commercialising inventions and thus affects the decisions of firms to choose forward co-operation instead of vertical integration. The costs of fulfilling the requirements of the regulatory approval are highest in human health products, and consequently, all the drug discovery firms had adopted the business strategy of developing innovations and out-licensing the IPRs to their inventions to big pharmaceutical companies. An important precondition for this is a tight appropriability regime, that is, the innovators can benefit from their innovation through strong protection and the innovations can be codified in patents (Teece, 1986).

With regard to firm strategy, there were differences concerning the stage at which the inventions were out-licensed, and the decisions firms made about this were largely affected by how cash-stripped the firms were to further develop the products. The later these were out-licensed, the more money the firm obtained or were to obtain for successful final products. Financial constraints may thus weaken the relative bargaining power of small biotechnology firms and drive them to agree to less advantageous deals. This finding is close to what has been written on bargaining power and its effect on control rights in alliances between small research firms and larger corporations, with the exception that control rights were not examined in this study (Lerner and Merges, 1998). The firms did actually make money on property rights (patents), since the property right regime was tight and the rights well protected by patents.

In other application areas, even though these were often related to the pharmaceuticals sector, e.g., diagnostics and biomaterials, the business strategies were different from those in drug discovery. In studies on biotechnology, the pharmaceuticals sector is typically treated as one block, and it is an important finding of this study that this is not the case. Firms in areas other than drug discovery did not have to plan for an equally long and costly trial process before they could obtain product approval. Consequently, these firms typically built their business around a strategy according to which they intended to manufacture their products themselves. These firms aimed at niche markets, or alternatively, at conquering a small portion of big and highly competitive markets. The typical solution was an integrated firm where the firm adopted not only manufacturing but, in most cases, also marketing. There were, however, also mixed cases in which some of the functions had been subcontracted. In these application areas, the appropriability regimes are not quite as tight and they vary by the application sector. Following Teece (1986), if an innovation requires an extensive amount of tacit knowledge and specialised assets, such as in manufacturing, the firm can take time to build its own facilities and does not necessarily need to contract out the function. An important difference with regard to drug discovery is also the fact that even if a firm did contract out some functions, such as manufacturing or marketing, it maintained control of the different functions, while in drug discovery the incumbent large firms were responsible for the integration function and the small innovating firm obtained a front payment and potential future royalties for the innovation. The firm in charge of the integration function is the one that will reap most of the potential future returns.

The importance of the application segment was highlighted by the fact that companies that were both in drug discovery and in diagnostics (chemicals, services) applied different strategies for these two areas. In drug discovery, firms followed the strategies of other drug discovery firms, and in diagnostics, the pattern of more integrated firms.

On the basis of the study, it can also be inferred that the resources needed for and the ease of building large-scale manufacturing facilities were related to the choice of organisational form. When a product was oriented to very specific niche markets, in which volumes are not large, a company could more easily acquire the resources needed for building the manufacturing facilities through venture funding. Hence, a firm would

be more inclined to adopt vertical integration. Several small firms outside drug discovery were developing products for niche markets and could build their manufacturing facilities. In human drugs, the type of markets varied, but many of the products under development were aimed at diseases with a large potential market. The typical pattern was not to manufacture products but to license out the IPRs to the innovations. One drug discovery company planned to take a niche market drug up to the final product stage. Its plans were based on the availability of foreign venture funding and of future income to be obtained from out-licensing the IPRs in clinical phase III. This was deemed possible because the volumes of sales in this very specific drug would be very small.

When compared with studies carried out in other countries (such as those by Mangematin et al. (2003) and Niosi (2003)), the findings of this study may be specific to a small country in a couple of respects. Aside from a few service segments, the domestic markets are so small that most firms need to look for clients abroad. Irrespective of their business strategies, they have to be export-oriented. Further, in pharmaceuticals the domestic incumbents are few in number and relatively small. The pharmaceutical companies with sufficient resources to develop the new innovative products of small biotechnology firms are typically large multinational companies. However, some established national firms (food, chemicals, and pharmaceuticals) did expand into biotechnology in the 1980s, but due to the recession of the early 1990s or for other reasons, ended some of their activities in this sector. This led to the establishment of small spin-off firms originating from the established firms, whose activities are based on the innovations created and who employ staff trained in these established firms. These incumbents have not, however, made contracts with small innovative biotechnology firms for R&D development or other functions, and are thus not benefiting from, or contributing to, the creation of network externalities.

Table 1 illustrates how companies in different application segments are situated in terms of the stringency of the regulatory system and the size of their markets and subsequent need to build appropriate facilities.

Table 1 does not give an example of a company from the studied material with less stringent property rights and mass markets, since there were none. However, it provides a couple of potential examples. Table 1 summarises the fact that there is variety in the degrees of vertical integration and network solutions and that firms with large markets with both stringent and less stringent regulatory systems take on only one organisational form while firms with small, niche markets have mixed forms of organisation. The strategies can be linked to both the demand for and the availability of funding as well as the tightness of the property rights regimes. When the regulatory requirements are stringent and the markets are large, which encourages building large-scale facilities, the need for resources is great. Even though most studied firms had obtained venture funding in one form or another, it was in most cases very small, with the foreign venture funding firms providing the largest and the regional ones the smallest sums. The limited resources of the domestic venture funding organisations constitute yet another feature specific to the Finnish context.

The stringency of the regulatory system seems to coincide with the tightness of the appropriability

Table 1
Forms of organisation by stringency of the regulatory system and market size

Product markets	Stringency of the regulatory system	
	More stringent	Less stringent
Mass markets	Organisational form based on *network firm*: developing innovations and out-licensing IPRs *Strong property rights regime*, e.g., drug discovery for common diseases	*Vertically integrated firm*, e.g., industrial enzymes, animal feed *From medium to strong property rights regime* (no examples in the data)
Niche markets	*Mixed organisational form A* based on developing innovations, out-licensing IPR and manufacturing, marketing *Strong property rights regime*, e.g., drugs for niche markets (brain tumours, etc.)	*Mixed organisational form B* based on vertical integration; with some firms having partial forward network solutions *From weak to medium strong property rights regime*, e.g., biomaterials, diagnostics, R&D and other services

regimes, which suggests their co-development. This can be understood in a way that if the resources invested in the product approval process are large, securing IPRs becomes more important than when this is not the case. We clearly need more research on IPR systems and their functions in the various application segments in biotechnology.

5.2. *Backward collaboration*

The study confirmed previous findings about the prevalence of university collaboration for small biotechnology firms. Practically all companies collaborated and a large proportion of their partners were domestic, many even from a local university. A lot of the university collaboration, especially that related to knowledge sourcing, was informal and it was possible to trace it back to old collegial networks. Thus, this confirms the findings of Liebeskind et al. (1996) that for new biotechnology firms, social networks are vitally important for knowledge sourcing. The informal networks were, however, the basis on which more formal contracts were negotiated. Formal contracting turned out to be of vital importance for an undisputed attribution of the ownership of immaterial rights or the right to commercialise findings, which is in accord with the findings of Zucker et al. (1998a). Irrespective of whether the firm intended to manufacture the final product itself or to out-license the IPRs, securing the immaterial rights to the firm was the basis for any further business transactions.

6. What is a network company?

In the foregoing analysis, the meanings of networking have been manifold: searching for new knowledge at universities through informal contacts, making formal R&D contracts, subcontracting manufacturing or marketing, subcontracting analyses/services, and outlicensing IPRs to an innovation with varying degrees of R&D collaboration. It is common to all of them that some of the phases of the process from discovery through product development and manufacturing to marketing and the various processes in between have been contracted out or done in agreement with another organisational entity. It is thus a question of vertical disintegration. An alternative organisational arrangement is a vertically integrated firm which is in charge of all these functions. In the biotechnology firms examined in this study, vertical integration was often resorted to in application segments outside drug discovery. Vertical integration versus disintegration thus changed across different activity areas in which a firm was engaged, but also over time.

Overall, various degrees of network solutions, or in the words of Powell (1998), "a portfolio of ties to specific partners for certain activities", abounded. However, practically all the individual ties studied were bilateral, though a single company had many bilateral ties or relations, usually based on formal contracts, with a variety of partners. The only examples of multilateral ties in the data were groups of researchers who founded a particular firm or made an informal agreement to use it as a vehicle for commercialising their inventions. Our study proposes that among small firms in biotechnology these ties are mainly vertical in contrast to horizontal ones and between two partners at a time rather than multilateral. The situation is probably very different in other sectors such as ICT where standardisation requires the formation of horizontal collaboration and forums consisting of multiple partners.

In the research literature, the term 'network' has been used in yet another way, namely as an alternative to the dichotomy of markets and hierarchies as forms of economic organisation. According to Williamson (1991), the network is a hybrid form within the market-hierarchy continuum, while Powell (1990) proposed that networks constitute a third form of economic organisation, one which emphasises "reciprocal patterns of communication and exchange" (p. 300). Trust created in such reciprocal relationships is an important means of avoiding opportunism inherent in uncertain contracts. According to Powell, networks constitute organisational forms that are "more social—that is, more dependent on relationships, mutual interests, and reputation—as well as less guided by a formal structure of authority" (Powell, 1990, p. 300). Contracting and property rights form the normative basis of the market type of organisation while employment relations characterise that of the hierarchy (Powell, 1990, p. 300).

In further research on biotechnology, Liebeskind et al. (1996) used the term of social network relationships for relationships similar to those Powell analysed. The importance of informal networks in social and economic activity overall and trust created in such

networks has attracted a lot of attention in recent years and has been coined social capital.[3]

Powell's schematic presentation of the three forms of economic organisation of course exaggerates and highlights the essential features in each. In practice, these features do not appear in pure forms, but in varying mixes. Thus, when interpreting Powell's term 'network' as less formal structures in relationships, as social relationships, or as contrasted with markets or hierarchies, our data among SMEs in biotechnology show that, aside from knowledge sourcing, where social networks are the principal pattern of organisation—also confirmed by Liebeskind et al. (1996)—'market' arrangements are dominant in other contexts. 'Market' arrangements here mean being regulated by formal contracts. Even in university collaboration 'market' arrangements become the rule when the commercial value of new findings becomes apparent. This has been noted also by Powell et al. (1996) and Zucker et al. (1998a). Our data suggest further that in forward collaboration 'market' arrangements, that is, contracts and licensing agreements, are central for organising the relations between firms. In accord with this, Arora and Gambardella (1994) have argued that network types of governance structures cannot do without property rights and the mediation of contracting.

The findings of this study and earlier research thus suggest that in collaboration among firms and universities and in firm-to-firm relationships, contractual and formal relationships are an important foundation for commercial activities. We may, however, presume that in collaboration and alliances that are controlled by formal contracts, informal social relationships constitute the foundation on which formal contracts and joint work is built. It is important to emphasise that a minimum degree of trust is needed for concluding contracts. Informal social relationships are, however, a feature that is present in varying degrees, but the purely non-contractual organisation of a network is a rarity in biotechnology. Thus, in Powell's sense, a 'network' company is an ideal type, and as such, rarely to be found in reality, at least in biotechnology, where, because of long lead times, uncertainty and high risks, securing the immaterial rights plays such an important role in the provision of value for the business.

[3] Social capital has been equated with social networks and trust, and the normative rules and mutual expectations underlying collaboration in social networks (Ruuskanen, 2001). Dasgupta (2002) considers social capital as a system of interpersonal networks (p. 35), which are a means to create trust needed in cooperation. Social capital is needed to build up feasible co-operative relations and it is further reinforced in co-operation.

7. Conclusions

This study examined the forms of organisation of small biotechnology firms in terms of their vertical integration versus disintegration. It found that when the application area had a stringent regulatory (product approval) system, as in human drugs, and the products were aimed at large markets, the form of organisation tended to be a network firm. With less stringent regulatory systems and niche markets, the form of organisation was more mixed or vertically integrated. The data used in this study were based on a limited sample of firms interviewed, and thus we may pose the question of the extent to which the findings are robust and hold true for different samples of firms or for firms in different stages of maturity.

First, the study is explorative and its findings are tentative and need to be confirmed in other studies. Second, it is to be noticed that, when faced with a given situation, firms may indeed adopt different strategies. This is evidenced by the finding that there was variation in the organisational form in the situation of less stringent regulatory system and niche markets. Nevertheless, the constraints imposed on the firms by their need of resources to develop their products and build the facilities clearly affect their choices of organisational forms. Still, we may presume that a lot of what has been said is valid particularly for firms in their early stages of development. Their needs for resources are most pressing at this stage when many of them still do not make revenues, or if they do, these are not sufficient for their product development needs. We may assume that in areas other than drug development, the more mature the firm, the more often vertical integration is adopted as an organisational form. Drug development will probably remain a field in which few biotechnology firms will grow into big vertically integrated firms simply because of the enormous costs this would entail and due to extremely heavy competition in the worldwide pharmaceutical market.

These findings have some policy implications. A network firm not involved in manufacturing or market-

ing will not have the same potential for quick growth as a vertically integrated firm, since it will not reap all the potential economic returns to its innovations, if and when these turn out to be successful in the markets (particularly if it is not in charge of the integration function). Further, if the network firm is an important organisational form of firms in a high technology area such as biotechnology, the location of the partner firms influences where major economic returns will accrue. When the majority of these firms are located abroad, as may be the case for a small country, major economic returns will go elsewhere. As expressed by Teece, this highlights "the importance to innovating nations of maintaining competence and competitiveness in the assets which complement technological innovation, manufacturing being a case in point" (Teece, 1986, p. 304). If manufacturing and marketing assets are situated outside the country, its economy may not benefit from investments in R&D as much as in the opposite case. This may turn out to be the case for Finland, where, since the late 1980s, research funding agencies have invested vast sums of public money in biotechnology R&D and the commercialisation of research results, with few economic returns so far (see Luukkonen and Palmberg, 2004). It is true that the sector as a whole, even in other countries, is still in its early stages of maturity, but the possibilities to capture economic returns may differ from country to country. Finland lacks major industrial firms ready to take on the large-scale industrialisation of biotechnology innovations, and small biotechnology firms are looking for partners in other countries. This situation questions the basic assumptions underlying the past policies in supporting and promoting the area, and it may turn out that the expectations, on which the policies have been built, turn out to be unrealistic.

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Appendix A. Characterisation of the interviewed firms by application segment

Company	Year founded	Functions the firm has adopted (based on actual or planned activities)	Venture funding source	Nature of university collaboration	Patents or patent applications
Drug discovery firms					
A (drugs, diagnostics, services)	1984	Developing innovations/out-licensing IPRs; manufacturing; marketing; services	National Venture Fund; Regional Venture Fund	Formal	Yes
B (UK owner)	1993	Developing innovations/out-licensing IPRs; manufacturing; marketing	Foreign Venture Fund; National Venture Fund	Formal	Yes
C (animal drugs animal vaccines)	1994	Developing innovations/out-licensing IPRs		Formal; informal	Yes
D (drugs, chemicals, diagnostics) (US owner)	1996	Developing innovations/out-licensing IPRs; manufacturing through a subcontractor; marketing (markets divided geographically with owner)	National Venture Fund; Public Venture Fund; Foreign Venture Fund	Formal	Yes
E	1996	Developing innovations/out-licensing IPRs	National Venture Fund; Public Venture Fund; IPO	Formal	Yes
F	1997	Developing innovations/out-licensing IPRs	Public Venture Fund; National Venture Fund; Regional Fund; Foreign Venture Fund	Formal; informal	Yes
G	1997	Developing innovations/out-licensing IPRs	Public Venture Fund; National Venture Fund; Regional Venture Fund; Foreign Venture Fund	Formal	Yes
H	1998	Developing innovations/out-licensing IPRs; manufacturing semi-finished products for other firms	Public Venture Fund; National Venture Fund	Formal	Yes

Appendix A (*Continued*)

Company	Year founded	Functions the firm has adopted (based on actual or planned activities)	Venture funding source	Nature of university collaboration	Patents or patent applications
Diagnostic firms					
A	1985	Manufacturing; marketing		Formal; informal	Yes
B	1990	Manufacturing; marketing; import: services			Yes
C	1994	Manufacturing; marketing		Formal	Yes
D	1996	Manufacturing, partly through subcontractors; marketing; services	Regional Venture Fund	Formal; informal	Yes
E (US owner)	1996	Manufacturing; marketing	National Venture Fund: Public Venture Fund	Formal	Yes
Biomaterials firms					
A (US owner)	1985	Developing innovations/out-licensing IPRs; manufacturing; owner markets	Public Venture Fund; IPO	Formal	Yes
B	1995	Developing innovations/out-licensing IPRs			Yes
C	1996	Developing innovations/out-licensing IPRs; manufacturing; marketing	Public Venture Fund	Formal	Yes
D	1997	Manufacturing; marketing	National Venture Fund: Regional Venture Fund; Foreign Venture Fund	Formal; informal	Yes
E	1999	Developing innovations/out-licensing IPRs; manufacturing (in future also brand manufacturing to others); marketing	National Venture Fund: Foreign Venture Fund	Formal	Yes
Services					
A	1995	Consulting; services		Informal	No
B	1997	Consulting; services			No
C	1998	R&D services	Public Venture Fund	Formal; informal	No
D	2000	Services; manufacturing; also subcontracting to others; marketing		Formal; informal	No
E	2000	R&D services	Regional Venture Fund	Formal	No
Food and feed					
A	1993	Manufacturing; marketing through subcontracting to distributors	Public Venture Fund; Regional Venture Fund	Formal; informal	Yes
B	1997	Developing innovations/out-licensing IPRs; test manufacturing through subcontractors	National Venture Fund	Formal	Yes
Miscellaneous					
A (instruments) (US owner 10%)	1994	Manufacturing through subcontractors; marketing by the owner	Public Venture Fund	Informal	Yes
B (enzymes)	1999	Developing innovations/out-licensing IPRs		Formal	Yes
C (bioinformatics)	2001	Manufacturing; marketing; services	National Venture Fund	Formal	Yes
D (drug delivery)	2001	Developing innovations/out-licensing IPRs; manufacturing through subcontracting; marketing through a partner	National Venture Fund: Public Venture Fund	Formal; informal	Yes

National Venture Fund = private venture fund operating nationally; Regional Venture Fund = private venture fund operating regionally; Public Venture Fund = public venture funding organisation operating nationally, in practice, Sitra. Sitra is an independent public fund under the responsibility of the Finnish Parliament. Its operations are mainly financed through income from endowment investments and project finance. Sitra has an important role in the development of business based on knowledge and know-how. Public equity investment for the start-up and early stages of companies is concentrated in Sitra. Foreign Venture Fund = private venture fund based abroad. A firm may obtain funding from several funds belonging to a class. In that case, it is only mentioned once.

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Appendix 8. Projected Growth Effects of the Biotechnology Industry in Finland

Hermans, R. – Kulvik, M. (2005). Projected Growth Effects of the Biotechnology Industry in Finland: The Fourth Pillar of the Economy? *International Journal of Biotechnology*, vol. 7, no. 4, 269-287.

Projected growth effects of the biotechnology industry in Finland: the fourth pillar of the economy?

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Abstract: This study assesses the impact of the Finnish biotechnology industry on economic growth in Finland. The study employs official data from Statistics Finland and new survey data covering 84 Finnish biotechnology companies. An econometric forecast for the economy-wide growth impact of the biotechnology industry in Finland is presented. In the estimation procedure, this study employs the survey data both in forming growth anticipations within a new emerging industry and assessing inter-industrial growth effects. Applied Monte Carlo simulations predict that the contribution of the biotechnology industry to annual GDP growth in 2002–2006 will be in the range of 0.05–0.09 percentage points per annum with a probability of 90%. These results imply that it will take decades rather than years for the biotechnology industry to become a fourth pillar of the Finnish economy beside the forest industry, the metal products and machinery industry, and the electronics industry.

Keywords: biotechnology; economic forecast; growth contribution; input–output model; monte carlo simulation.

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1 Introduction

1.1 Background

The expectations concerning the economic potential of biotechnology have grown during the last two decades in Finland. Biotechnology is anticipated to become an important driving force in the economy, after the era of information and communications technologies. Schienstock and Tulkki (2001) have even discussed whether the biotechnology industry could become a fourth pillar of the Finnish economy, next to the forest industry, the metal products and machinery industry, and the electronics industry.

In Finland, the number of dedicated biotechnology firms has grown rapidly in the 1990s and it is estimated to have one-tenth of such firms in Europe (Kuusi, 2001). The public sector has invested considerable resources in training and R&D in this field. Private investments and venture funding have also grown decisively (Hermans and Tahvanainen, 2002). The main application areas of biotechnology in Finland include pharmaceuticals, diagnostics, functional food, biomaterials, enzymes and the food and chemistry businesses, as well as services related to those fields (Hermans and Luukkonen, 2002).

Biotechnology is not easy to define as an industrial branch. OECD (2005) defines biotechnology as, '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'. Public attention is usually paid to small, dedicated biotechnology firms, but they are not the only ones to make and commercialise biotechnological discoveries. However, several well-established larger firms are also involved in biotechnology R&D and commercialisation. The entire field is closely related to scientific research, where many of the discoveries are made. The commercialisation of the discoveries is, however, uncertain and the process is slow compared with, for example, the information and communications technologies (Luukkonen and Palmberg, in press).

The high-risk nature of the development processes of the biotechnology industry must be taken into consideration when forecasting its economic impacts. The delays in the development processes of biotechnology companies, as well as the risk of technological failure, have to be included as part of the forecasting model.

1.2 Objectives and motivation of the study

Despite the high investments and expectations regarding the biotechnology sector, there are only a few studies estimating the short-term economic growth impacts of the sector. It is well known that biotechnology firms report high growth potential for sales, but the spillover effects on other industrial branches and the growth contributions to the gross domestic product (GDP) have not been studied. Ernst and Young (2000) analysed the growth contributions of the biotechnology industry in the USA for 1999, using the

input–output model. However, the study focused only on existing official data classifications, and the latter do not necessarily meet the target, that is, the biotechnology industry.

The objective of the present study is to assess the impact of the Finnish biotechnology industry on economic growth in Finland. The assessment uses a forecast model based on data derived from two sources:

- the official data from Statistics Finland
- new survey data covering 84 Finnish biotechnology companies and their declared future sales.

However, there were two major obstacles to overcome in the construction of a forecast model. First, biotechnological applications span several statistical subgroups in the official statistical classification; thus the conventional statistical categories are not applicable for this new, emerging industry – the official statistics and classification procedure within the area are still under construction in the OECD. Second, the anticipated future sales disclosed by the biotechnology companies do not fully reflect the exceptional risks related to both the technological feasibility and delays in research and development processes.

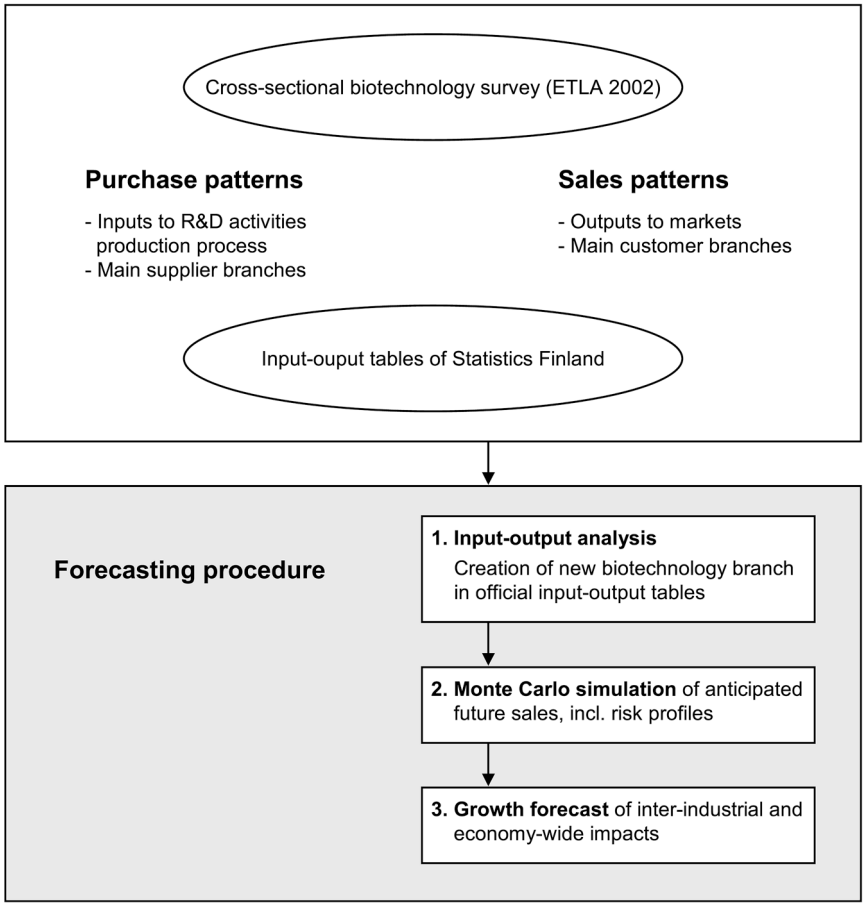
In order to overcome the first obstacle, it was necessary to create a new industrial class of biotechnology in the conventional input–output table of Statistics Finland. The second obstacle was overcome by the application of the Monte Carlo simulation, which simultaneously allows the implementation of the stochastic features of failure versus success, and the probability distributions for anticipated future sales of the biotechnology companies.

1.3 Research procedure

The forecasting procedure consists of three phases (Figure 1):

- Input–output tables estimating linkages to other industries are formed on the basis of survey data covering production and patterns of purchases and sales in the biotechnology industry.
- The biotechnology sector is added to the official input–output tables of Statistics Finland as a new branch. This enables the estimation of backward linkages to other industries. The backward linkages depict how much the biotechnology sector increases purchases from other branches when its own sales grow, and vice versa. This enables estimation of the economy-wide growth potential; the estimation is based on the Monte Carlo simulation using probability distributions of firms' anticipated future sales and bankruptcy risk during 10,000 iterations.
- The results of forecast impacts are presented and discussed in the context of the Finnish economy.

Figure 1 Framework of the forecast model



The biotechnology sector is classified under many statistical branches in official statistics (e.g. chemical production, foodstuff production, business services). The biotechnology companies as a group, however, differ from other Finnish companies on average (Hermans, 2004; Hermans and Tahvanainen, 2002). For example, there are many biotechnology companies that do not have sales yet, but which expect to have high sales in the future, based on the relatively high expenditure on research and development (R&D) activities. The input–output tables of Statistics Finland did not include the biotechnology sector as an entity. Hence, it was necessary to use separate survey data in order to be able to estimate the input–output structures of these companies and their inter-industrial linkages and economic impacts. The survey data included information for 2001 that small- and medium-sized biotechnology companies had themselves announced about the input–output structures (patterns of purchases and sales). The companies also disclosed their sales expectations.

However, most large biotechnology-related companies did not reveal their patterns of purchases and sales. Consequently, they could not be included in the new statistical

branch of the biotechnology industry described above. The majority of the large companies represent more mature entities compared to the small- and medium-sized biotechnology enterprises (SMEs); thus, their input–output structures are closer to the average industrial classes than the biotechnology SMEs are. The large companies are therefore treated as part of the existing statistical classes.

Input–output modelling reveals supply and demand linkages between different branches. An industry uses the outputs of other industries as intermediate inputs in its own production processes. The industry sells its own output to another industrial branch, which uses that, in turn, as an intermediate input in its production. Input–output tables conclude these inter-industry linkages; they have been used in many contexts, such as industrial forecast models (Burridge, 1991), regional forecast models (Rickman, 2001) and forecasting the dynamics of production within a pharmaceutical company (Marangoni and Fezzi, 2002).

The word 'simulation' refers to any analytical method which attempts to imitate a real-life system; usually other types of analysis are mathematically too complex or too tedious to produce (Drakos, 1995). One type of simulation is the Monte Carlo simulation, which randomly generates values for uncertain variables to create a forecast using numerous iterations. The Monte Carlo simulation is used in a multitude of applications; examples are in nuclear reactor design, radiation cancer therapy, traffic flow, oil well exploration and econometric Dow-Jones forecasting (Drakos, 1995). Monte Carlo simulation has also been used in the estimation of the input–output models (Bullard and Sebald, 1988; Roland-Holst, 1989).

This study constructs input–output multipliers from the cross-sectional data, and the simulation is utilised in the forecasting procedure. Without the use of simulation, an input–output model would result only in a single outcome: a scenario in which all the positive expectations of the biotechnology companies are realised. However, such a scenario does not reflect the most probable outcome.

The forecast procedure presented here uses both the input–output model and Monte Carlo simulation to numerically analyse the effect of varying uncertainty factors. The first factor is the threat of bankruptcy. It is defined as a stochastic outcome: bankruptcy, or continuing business at the end of 2006. Exogenous foreign demand constitutes the second uncertainty factor. It is included as a probability distribution of anticipated exports by the Finnish biotechnology companies. These uncertainties are included in the simulation. Instead of a single outcome, the model produces a distribution of all the potential outcomes given the assumptions behind the initial probability distributions. The assumptions are discussed in detail below.

The rest of the paper is divided into three sections. Data employed in this study and assumptions behind the model are examined in Section 2. The input–output relations between the biotechnology sector and branches that use biotechnology in their processes and products, or that are suppliers to the biotechnology firms, are also depicted. Section 3 employs a numeric Monte Carlo simulation-based input–output analysis to construct a growth contribution scenario for the Finnish economy as a whole. Section 4 summarises the results of the forecast and relates the projected growth of the biotechnology industry to the three main pillars of the Finnish economy.

2 Biotechnology industry in Finland

2.1 Data

This study employs a survey conducted by ETLA, the Research Institute of the Finnish Economy (Hermans and Luukkonen, 2002). The survey contains financial and business activity information on 84 Finnish biotechnology firms, which raised some concerns. There were 131 biotechnology firms active at the end of 2001, and thus the survey data represent only 64% of the sector. Furthermore, the sample seems to be slightly biased toward the older age groups: the sample contains 75% of the companies founded during 1991–1996, as well as companies founded earlier than 1991, but only 49% of the companies founded during 1997–2001 (Table 1). In order to form a plausible estimation for depicting the entire biotechnology sector in Finland, weights were constructed reflecting the age groups of the firms; the weights are inverses of the percentage shares of the sample in different age groups.

Table 1 Number of biotechnology firms in the sample of the ETLA survey respective to total population sorted by age groups

	Before 1991	*1991–1996*	*1997–2001*
ETLA sample	25	34	25
Total number	34	46	51
Percentage share of sample (%)	74	74	49
Weight	1.36	1.35	2.04

The survey contains information on the purchase and sales patterns of 72 SMEs: the input pattern, i.e. the main branches from which they purchased intermediate inputs, and output pattern, i.e. the main branches to which the companies sold their products and services. This information was integrated as a new branch in the official input–output tables of Statistics Finland. The SMEs disclosed only their three most significant trading branches, and thus there was not enough detailed information on all of the subclasses. This problem was eliminated by aggregation of branches, in which the entire input–output table was condensed to a 7×7 table.

Large companies did not disclose detailed information about their purchases and sales, and were therefore classified into the conventional industrial and service branches best fitting their activities. The existing structures of the branches of large companies were assumed to adequately illustrate input–output patterns of the latter. The large companies are often multifunctional in the sense that they also have more conventional products. Our forecasting is based on the share of biotechnology-related sales disclosed by the companies, not their entire conventional production.

A stochastic feature was included in the forecasting model. A discrete dichotomous setting for the probability of going bankrupt was added to the model. The bankruptcy risk was set at 5.7% for SMEs according to US experience in the biotechnology industry, and 1% for large-sized firms (Boehm and Schuehsler, 2003). In Finland, the relative share of bankruptcies has been slightly above 5%, according to the ETLA biotechnology database.

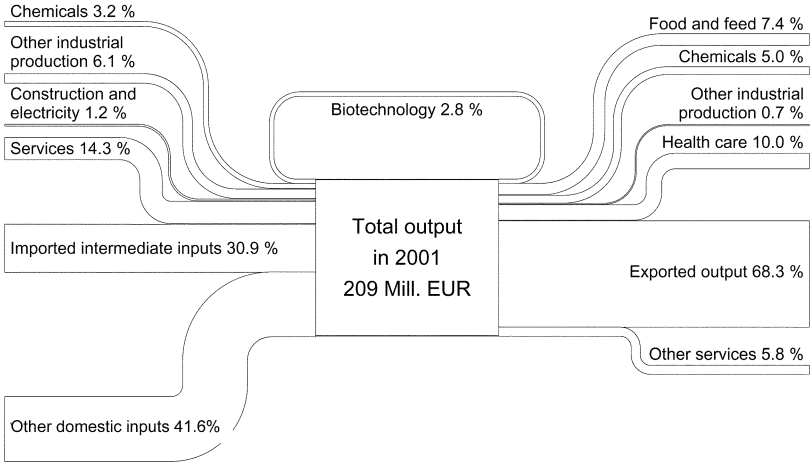
The growth forecast was based on the firms' estimates of future sales. All biotechnology firms expected growth in the next five years, between 2002 and 2006. The estimation of exogenous foreign demand set into the input–output model was based on the anticipated future exports disclosed by the companies (Table 1).

The firms' estimates were modified with probability distributions in order to create weighted anticipated future exports for each firm. All the firms were assumed to face the same risk of either delays in entering the marketplace with new products, or of a market penetration that would not evolve as optimistically as expected. Thus, the estimates for the probable anticipated future sales were arrived at by applying a uniform distribution. The lower limit of the uniform probability distribution was set by current exports (in the end of 2001). The upper limit was set by the anticipated future exports in 2006 as announced by the company. Finally, a Monte Carlo simulation with 10,000 iterations was run using the parameters above.

2.2 Input–output structure

The Finnish biotechnology industry is based on intensive international relations and foreign trade; two-thirds of the sales are exported and almost one-third of the purchases are imported (Figure 2). The biotechnology industry purchases most of its domestic intermediate inputs from the service sector. Other domestic inputs contain the wages of labour and the profits or losses of the companies. The great losses, almost EUR 100 million in 2001, reduce the net domestic inputs. The inputs add up to EUR 209 million.

Figure 2 Input–output structure of the Finnish small and medium-sized biotechnology companies



In input–output models, inputs always equal outputs, and thus total output is EUR 209 million. The largest domestic customer branches to which the output is sold are healthcare services, the food and feed industry and the chemical industry (including pharmaceuticals). Over 60% of the total output of services and products are exported. Thus, the foreign trade intensity is relatively high within Finnish biotechnology SMEs.

2.3 Growth prospects

Biotechnology firms are active in many industrial sub-branches. Most of the companies are related to pharmaceuticals, diagnostics, or both. There are also a significant number of firms involved in service activities, biomaterials and the food industry. A few of the companies are focused on enzyme production or agriculture.

The biotechnology companies seem to anticipate high growth in demand for their products. The global market potential appears to be particularly attractive. Table 2 presents the anticipated growth rates of sales of the Finnish biotechnology industry by sub-branches.

Table 2 Anticipated annual growth rates of biotechnology sales of products and services for the next 5 consecutive years, as anticipated by the Finnish biotechnology companies at the beginning of 2002

Growth rate (%)	*Domestic sales (%)*	*Exports (%)*	*Entire sales (%)*
Pharmaceuticals	4	36	22
Diagnostics	4	17	14
Biomaterials	17	94	49
Food and feed	3	11	7
Industrial enzymes	7	5	5
Agriculture	21	24	23
Services	12	101	38
Other	6	19	18
Total	7	27	21

The table shows how the growth prospects vary among each sub-branch of the biotechnology sector. The average anticipated growth over the next five years is 21%. It is expected that growth will be realised mainly in international markets. Most of the firms expect that they can exploit a market potential throughout the world.

A rather surprising finding is that the enzyme-related industry expects only a moderate 5% growth. Finland is regarded as a giant in pulp and paper production, which is a heavy user of enzymes, and thus it would be expected to stimulate the demand for new enzyme applications (Laestadius, 2000). At the other extreme, biomaterials production is anticipated to grow by almost 50% annually.

The forecast procedure utilises the companies' expectations regarding their future export growth. However, using the companies' own expectations introduces two possible types of bias to the model:

- randomness at the company levelóan arbitrary assessment of anticipated future exports
- systematic error at the industry level – a tendency of the entire biotechnology sector to overestimate the level of anticipated future exports over the period of the survey.

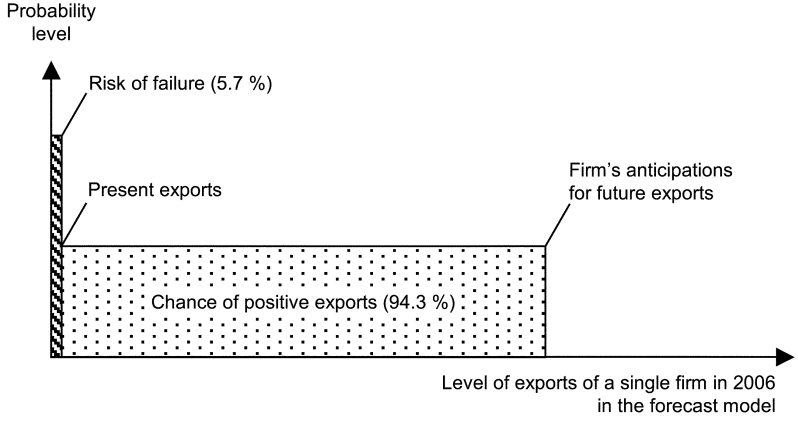
Hermans and Kauranen (2005) have analysed the first type of bias. They related the measurable intellectual capital factors to the anticipated future sales of the biotechnology

SMEs in Finland. The intellectual capital theory suggests that the interrelation of human, structural, and relational capital acts as a driver for value creation in a knowledge-intensive business (see Edvinsson and Malone, 1997). In the study Hermans and Kauranen constructed an intellectual capital model that explained 70% of the variance in anticipated future sales. Consequently, measurable intellectual capital was tightly related to the anticipated future sales of the biotechnology SMEs: if a company holds a relatively high (or low) level of well-balanced intellectual capital, it also has high (or low) growth expectations, respectively. Therefore, it seems well-reasoned to rely on the companies' expectations in the ordinal sense, that is, the companies with the highest anticipated future sales are those that have a high level of intellectual capital and that will therefore probably sell more than those with lower expectations.

Despite the ability to explain the variance of anticipated future sales of the biotechnology SMEs, the second bias remains. There are two main reservations. The first is related to the high risk in developing new biotechnology innovations, and particularly in converting them into commercially exploitable products. Second, there are doubts about the expected short time interval (here 2002–2006) for converting large losses into a flourishing business. The companies seemed to disclose their anticipated future sales within the most optimistic scenario, probably omitting the possibility of technical failures or severe time delays in product development.

In order to control for the second bias, probability distributions were applied while forecasting the economic impacts: a discrete probability distribution covers the bankruptcy risk, and a uniform distribution covers the sales expectations between the present and anticipated future exports (Figure 3). In other words, there is a 5.7% chance that a single firm will go bankrupt and 94.3% chance that its exports will be between the exports of 2001 and the anticipated future exports for 2006.

Figure 3 Probability distribution of an individual firm's exports



3 Economic forecast

3.1 Input–output analysis

The econometric modelling procedure is initiated by input–output analysis. Input–output tables (for a variant, see Table 3) are utilised in order to estimate growth prospects

covering inter-industrial linkages as well as contributions to the whole economy until the end of 2006. A conventional Leontief-type input–output matrix was constructed (Ciaschini, 1989; Forssell, 1985). The input–output model describes the inter-linkages between all branches of industry.

Table 3 Inverse matrix derived from input–output table

Inverse matrix	*Agriculture and other primary production*	*Biotechnology*	*Food industry*	*Chemical industry*	*Other industrial production*	*Construction and electricity*	*Healthcare services*	*Other services*
Agriculture and other primary production	1.2410	0.0084	0.4465	0.0310	0.0637	0.0422	0.0064	0.0151
Biotechnology	0.0002	1.0518	0.0020	0.0018	0.0001	0.0001	0.0013	0.0002
Food industry	0.0641	0.0082	1.2768	0.0294	0.0193	0.0159	0.0085	0.0223
Chemical industry	0.0247	0.0363	0.0178	1.0772	0.0263	0.0131	0.0092	0.0051
Other industrial production	0.0966	0.1028	0.2030	0.1995	1.3697	0.3564	0.0617	0.1202
Construction and electricity	0.0494	0.0263	0.0460	0.0484	0.0362	1.0779	0.0245	0.0652
Healthcare services	0.0111	0.0034	0.0052	0.0014	0.0016	0.0017	1.0239	0.0054
Other services	0.2439	0.2260	0.3688	0.2765	0.2640	0.3295	0.1898	1.3531

Horizontal rows refer to the usage of the output of a single industry in the form of intermediate inputs in production processes of other industries, and as end products to satisfy the domestic and foreign demand. Vertical columns depict how much an industry uses intermediate inputs from other industries and imported inputs, and how much value-added it produces. The method used in this study assumes that these structural multipliers, depicting the shares of input and output usage out of output, are fixed over the period that is analysed. Equation 1 states the above relation formally:

$$x_i = \sum_{j=1}^{n} a_{ij}\, x_j + y_i \text{, or in vector notation: } X = AX + Y. \quad (1)$$

The multiplier a is derived from a ratio:

$$a_{ij} = \frac{x_{ij}}{x_j},$$

in which x_j is the total (intermediary and final) output produced by the industry. The term x_{ij} measures how much the industry j uses the production of the industry i as an input. When i equals j, the multiplier a measures the intermediate inputs used within the companies from their own industrial branch. The term y denotes a value of end products in an industry ($1,\ldots,n$). Capital letters without subscripts are matrix notations referring to the terms above.

Because $X=AX+Y \Leftrightarrow Y=(I-A)X \Leftrightarrow X=(I-A)^{-1}Y$. Therefore,

$$x_i = \sum_{j=1}^{n} b_{ij}\, y_j \text{, or in vector notation: } X = (I - A)^{-1} Y. \quad (2)$$

The term b_{ij} expresses how much industry i needs to produce so that industry j could produce one unit of final product.

These matrix operations enable the use of the multipliers of the inverse matrix when estimating the effects of the growth in the biotechnology industry in Finland. The input and output structure of SMEs were added to the model as a new branch. Large-sized enterprises were treated as a part of their conventional branch because they did not disclose any information on their purchase and sales patterns.

Table 3 depicts the inverse matrix derived from the general form of Equation 2. The coefficients are interpreted as follows. The exogenous increase of one unit in demand of biotechnology products and services will add 1.0518 units to the total output of the biotechnology industry due to the usage of intermediate products from the companies in its own industry. A one-unit increase in the output of the biotechnology industry is reflected by a 0.226-unit increase in the demand for other services (vertical column 'Biotechnology' in Table 3). However, only 0.0002 units of biotechnology outputs are produced for the other services (horizontal row 'Biotechnology' in Table 3).

Table 3 shows that an exogenous change in demand for the output of other sectors results only in a negligible increase of demand for the biotechnology products and services (horizontal biotechnology row). This reflects the fact that the biotechnological applications are not yet tightly linked with other sectors' production processes. For example, a one-unit increase in the production of healthcare services induces only a 0.0013-unit increase in purchases of inputs from the biotechnology industry.

The input–output linkages can and probably will vary with time. For example, biotechnology products can replace some conventional chemical products in consumer and intermediate input markets, leading to an increase in the coefficients of the biotechnological inputs in the inverse matrix. However, this replacement, or crowding-out effect is not taken into account in the fixed coefficient input–output model based on cross-sectional data.

The multipliers are estimated from the cross-sectional data obtained through the ETLA biotechnology survey. The survey is the first of its kind in Finland. Thus, time series data are not available for the Finnish biotechnology sector, which at the moment excludes the construction of a time series model.

3.2 Monte Carlo simulation

This section presents the results of two simulation procedures. The first simulation contains only the predicted growth impacts of biotechnology SMEs on other industries. In addition to SMEs, the second simulation contains also the large biotechnology-related multifunctional companies. The twofold approach was necessary in order to avoid blurring between the inter-industrial linkages and growth contribution to Gross Domestic Product (GDP).

The input–output model estimates spillover effects, and thus it reveals the impact of potential growth in the biotechnology industry on other sectors in the table. However, the spillover effects could not be assessed with a single simulation, because the large companies are part of the official branches, and SMEs are part of the newly-formed

branch of the biotechnology industry. The first simulation, containing only SMEs, indicates how large the spillover effect is on other branches.

The second simulation, which contains also the large biotechnology-related companies, enables the estimation of the growth contribution of the entire biotechnology industry to GDP. However, it does not offer an insight into the spillover effects on the specific branches since the output growth effects of the large companies and spillover effects cannot be distinguished from each other.

3.2.1 Results of simulation 1

The value-added of biotechnology SMEs was approximately EUR 90 million in 2001. According to the results of our forecast model, the predicted nominal growth contribution of the biotechnology SMEs to the GDP in 2006 will be in the range of EUR 165–414 million, with a 90% probability (Figure 4). This corresponds to an annual average growth contribution of 0.02–0.06 percentage points from 2002 to 2006. This prediction contains the multiplier effects from input–output tables on both biotechnology and non-biotechnology branches. The value-added of the biotechnology SMEs is predicted to be EUR 125–309 million in 2006, with a 90% probability.

Figure 4 Distribution of the forecast nominal contribution of the small biotechnology industry to GDP in 2006

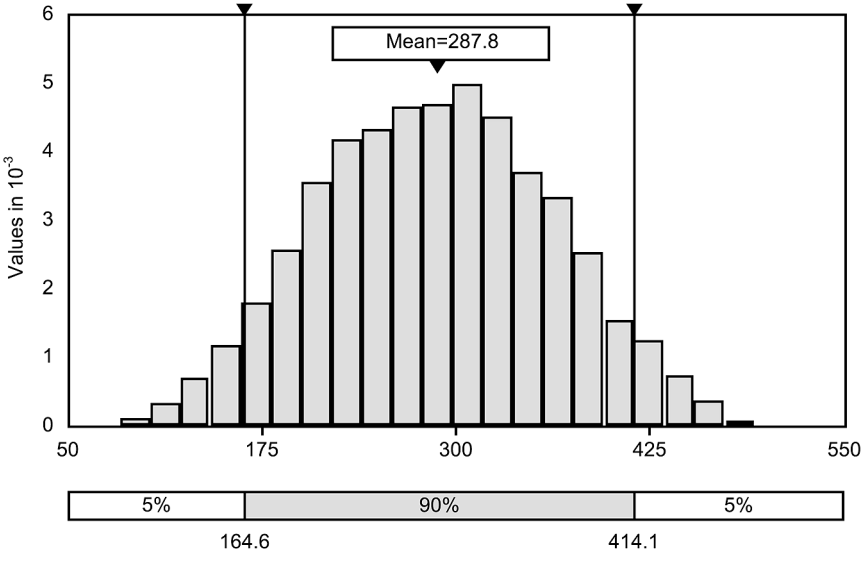


Table 4 presents the main results of the forecast procedure. The overall contribution of the biotechnology business is slightly positive for the economic growth in Finland. As mentioned above, the gross domestic product (GDP) is expected to grow an additional annual average of 0.02–0.06 percentage points through the impact of the growth of the biotechnology industry. The biotechnology industry is forecast to grow at an annual average of 18–34% during 2002–2006. The spillover effects produced by the biotechnology industry are distributed unevenly among other branches.

Table 4 Monte Carlo simulation-based anticipated nominal growth contributions of small and medium-sized biotechnology companies in annual terms

Branch	*1. Annual growth contribution to a single branch (2002–2006), percent, range of 90% probability (%)*	*2. Annual growth contribution to GDP (2002–2006), percentage units, range of 90% probability (%)*	*3. Nominal contribution to the growth of the value added in 2006, million euros, range of 90% probability*
Agriculture, forestry, and other primary production	0.01–0.02%	0.00–0.00	1–3
Biotechnology SMEs	18.1–33.7	0.02–0.04	114–286
Chemicals	0.04–0.09	0.00–0.00	3–7
Other industry	0.01–0.02	0.00–0.00	10–25
Construction	0.01–0.02	0.00–0.00	3–7
Services	0.01–0.02	0.01–0.01	34–86
GDP	0.02–0.06	0.02–0.06	165–414

The spillover effects are highest in the chemical industry, corresponding to an annual increase in production of 0.04–0.09 percentage points. The production of Other Industry (including production of instruments and food industry) is predicted to be stimulated by 0.01–0.02 percentage points on an annual average.

The service sector forms the largest sector in the Finnish economy; it produces 63% of the GDP. Despite a relatively low growth contribution of 0.01 percentage points, the contribution corresponds to EUR 34–86 million during 2002–2006; this is the largest contribution of any other branch in monetary terms. The impacts on construction, agriculture and forestry remain low, both as percentage points and in monetary terms.

As a whole, the model forecasts that a high relative economic growth of value-added in biotechnology SMEs will only have a low spillover effect on the entire economy over the next five years. There are two potential reasons for the low spillover effects. First, there is the lack of the input–output data for large companies in the survey. This has been discussed above. Second, the volume of purchases and sales was still very low in 2001. It must be born in mind that even a single company showing significant success and consequently purchasing higher volumes would have a significant impact on the entire input–output structure over time.

3.2.2 Results of simulation 2

The first simulation was followed by a second, in which the classification of the large biotechnology-related companies as a part of the conventional statistical branches reduces the aberrant effects that a single large company could have on the input–output structure of the entire biotechnology industry. The forecast model was constructed combining SMEs and large multifunctional biotechnology companies. The multifunctional companies are those that also have essential production activities in branches other than

biotechnology. All the large companies are placed in their conventional branches (not the biotechnology industry) in the input–output model.

The value-added of the entire biotechnology industry, with production that utilises biotechnology-based products or processes, was about EUR 500 million in 2001. The forecast model estimates that the growth of the entire biotechnology industry will contribute EUR 315–623 million to the growth of the GDP in 2006 (Figure 5), with a 90% probability. This corresponds to a growth contribution of 0.05–0.09 percentage points to the GDP growth rates per annum.

Figure 5 Distribution of forecast nominal contribution of the entire biotechnology industry to GDP in 2006

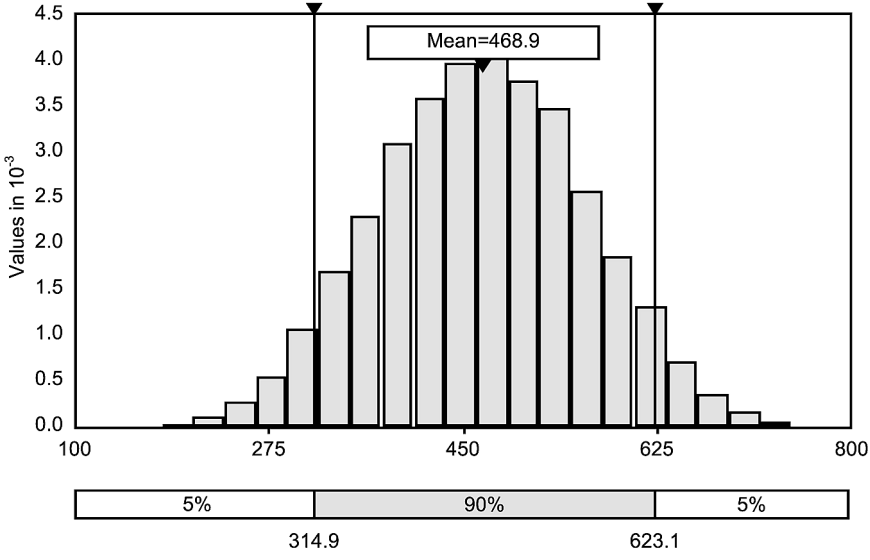


Table 5 presents the growth contributions of the entire biotechnology sector to other branches and to the total GDP growth. The impact on the production of chemicals and chemical products is greatest: the annual growth contribution of biotechnology-related value-added is forecast to reach the range of 0.18–0.99 percentage points. The entire biotechnology industry contributes to the growth of the production of Other Industry by 0.03–0.10 percentage points on average annually. Growth contributions to other sectors are not as significant.

The growth rates of production of a single branch can be very different from the growth contribution rates presented in Table 5. For example, the growth rate of value-added in agriculture and other primary production can even be negative during the years of the forecast and thus its contribution to the GDP would also be negative.

This study considers anticipated exports to be an exogenous variable. In other words, the increase in domestic demand resulted from an increase in the use of inputs in domestic production. If part of the domestic production had also been considered exogenous, the growth rates would have been slightly higher.

Table 5 Monte Carlo simulation-based anticipated nominal growth contributions of entire biotechnology industry (including large companies) in annual terms

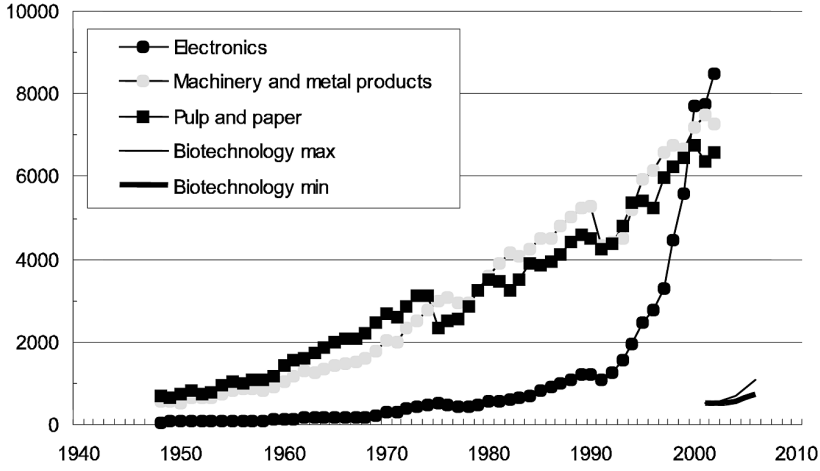
Branch	*1. Annual growth contribution to a single branch (2002–2006), percent, range of 90% probability (%)*	*2. Annual growth contribution to GDP (2002–2006), percentage units, range of 90% probability (%)*	*3. Nominal contribution to the growth of the value added in 2006, million euros, range of 90% probability*
Agriculture, forestry and other primary production	0.03–0.06	0.00–0.00	6–14
Biotechnology SMEs	18.3–33.7	0.02–0.04	115–285
Chemicals	0.18–0.99	0.00–0.01	15–81
Other industry	0.03–0.10	0.01–0.02	51–134
Construction	0.01–0.03	0.00–0.00	6–13
Services	0.02–0.04	0.01–0.02	79–155
GDP	0.05–0.09	0.05–0.09	315–623

3.3 Biotechnology – the fourth pillar?

Industrial history shows us that if a region or a country has no previous industrial tradition in a certain sector, successful businesses and new growth emerge slowly or only seldom. Finland has pinned high hopes on biotechnology as a source of new research-intensive growth. Almost all industrialised countries have the same goal, and many of them already have long traditions in this sector, whereas Finland has a short history in biotechnology. In Finland, the biotechnology sector's volume of production measured by value-added is slightly over EUR 500 million. In order to get a perspective on the growth possibilities, the biotechnology sector can be compared to the development of the currently strong sectors in Finland – the forest, machinery and electronics industries.

In the early 1950s, the value of pulp and paper industry production was EUR 500 million in year 2000 prices (Figure 6). The electronics industry reached that level in the mid-1970s. If the biotechnology sector achieved the same growth as that of the electronics industry, it would reach the position of the 'fourth pillar' of Finnish industry in about 30 years. If the life cycle of the biotechnology industry as an independent sector is comparable to the forest industry, the time span would be 50 years. Finally, if the growth rate of production of the biotechnology sector was sustained at the same level as in the forecast period 2001–2006, it would take 15–30 years to reach the same production level as the electronics, machinery and metal products, and pulp and paper industries have today.

Figure 6 Industrial production by sector 1948–2002, in year 2000 prices



4 Conclusions

4.1 Discussion

Technological evolution in healthcare related biotechnology can improve the effectiveness of treatment, with resulting positive human impacts, especially because of the aging of the population and the medical possibilities for diagnosing and treating more illnesses than before. The trade-off is in rising healthcare costs; this is considered to be one of the current core problems in the Western societies (OECD, 2004). However, biotechnology applications can also spawn cost savings over the long run by, for example, making time-consuming diagnostic methods more efficient and facilitating targeted therapy. Thus, special emphasis is put on thorough cost–benefit analyses when a new biotechnological innovation is presented.

However, technological evolution does not always induce additional costs in the traditional sense. For instance, the introduction of ultra-acute thrombolytic therapy has been shown to induce both remarkable improvements in the quality of life of stroke patients as well as significant savings for the healthcare system (for further discussion, see Hermans and Kulvik, 2004). Thus, despite a short-term increase in the costs of acute treatment using a new technology, larger long-term savings can be induced, for example through a reduction in rehabilitation expenditures due to a leap in the biotechnological evolution.

In such cases the fixed multiplier input–output framework has to be used cautiously, as it is based on historical economic data and can thus not foresee the impact of a technological evolution that changes the existing paradigm and thereby the input–output multipliers. However, the short forecasting period diminishes the risk created by large shifts in economic structures.

4.2 Summary

This forecast study is intended to offer insights on the impacts of the Finnish biotechnology industry on economic growth in Finland. The study focuses on converting

expected growth potential into impacts on economy-wide growth. The use of Monte Carlo simulation enables the use of probability distributions instead of point estimates in order to model risks related to the failure of a single company, as well as to time delays in its product development and market launches.

The present purchase/sales patterns of the biotechnology SMEs were added as a new industrial sector to official statistics. This procedure employed an input–output analysis, which enabled the estimation of economy-wide growth impacts. An inverse matrix with fixed multipliers was constructed, and the impact of exogenous foreign demand during 2002–2006 was assessed using a Monte Carlo simulation with 10,000 iterations.

The high percentage growth prospects of the Finnish biotechnology industry remained relatively moderate on an aggregate macroeconomic level. The growth contribution for the Finnish nominal GDP growth was 0.05–0.09 percentage points annually. This equals the growth impacts of EUR 315–623 million in nominal terms during 2006.

A noticeable impact on the chemical industry was seen. According to the simulations, the biotechnology companies add 0.2–1.0 percentage points to the annual nominal growth of chemical production in Finland. Many of the biotechnology firms act in chemical-related sub-industries.

Even with swift growth, it will take more than a decade for the biotechnology industry to become one of the main pillars of the Finnish economy. It is likely that the Finnish economy's new engine of growth will emerge from a combination of new and old sectors. In such a scenario, biotechnology would play a significant role.

4.3 Further studies

This study opens views for further research:

- The sub-branches of the biotechnology industry differ from each other concerning their risk profiles. For example, the predicted time span from innovation to product launch is exceptionally long in drug development as compared to development of biomaterials and industrial enzymes. The drug development is strictly regulated, requiring extensive pre-clinical and clinical testing before approval to initiate marketing. The Monte Carlo simulation can be refined by using sub-branch-specific risk profiles, which would add to the accuracy of the model.
- This study employed fixed input–output multipliers because only cross-sectional survey data was available. As time series become available, the changes of multipliers can be estimated over time using historical data. This would enable the incorporation of the evolvement of industrial structures into the model.
- Rantala (2003) indicated a change of input coefficients over time with the help of R&D intensities of industrial branches. In the R&D-intensive biotechnology industry, the inclusion of these dynamic procedures to the input–output models could offer another way of estimating the changes of input–output multipliers behind the forecast.
- This study does not analyse labour effects. However, the identification of labour effects induced by the growth of the biotechnology industry would be valuable in the macro-economic context (see e.g. Menrad et al., 2003, employing German data).

The forecast model presented in this study can be refined to support these four research set-ups.

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