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Living up to the Expectations Set by ICT? The Case of Biotechnology Commercialisation in Finland

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ABSTRACT *This paper examines the dynamics and bottlenecks in the commercialisation of biotechnology in Finland by using the Information and Communications Technology (ICT) industry as a benchmark. The paper considers both ICT and biotechnology within the dynamic life-cycle model of technological revolutions by Perez. For an empirical comparison, it applies the concept of a 'competence bloc' as an interpretive and focusing device. A competence bloc may be defined as a set of actors, functional competences, and institutions that are necessary for large-scale commercialisation and industrialisation of new emerging technologies. In spite of the many differences between the ICT and biotechnology industries, the comparison serves as a heuristic device for pinpointing important features in the framework conditions of commercialisation in biotechnology. The paper shows that a major bottleneck in the development of the biotechnology industry in Finland is the scarcity of industrialists to transform innovations into large-scale production.*

1. Introduction

1.1. Background and Aims

Since the late 1980s Finland has invested a large amount of public funds in biotechnology R&D and the commercialisation of research results. These investments have grown particularly in the latter part of the 1990s.[1] As a result, Finland witnessed rapid growth in the number of biotechnology firms in the 1990s, particularly towards the end of the decade. Nevertheless, these firms are to a large extent unprofitable and development of their products is still in an embryonic stage. The commercialisation of biotechnology has turned out to be more difficult than was foreseen when major public programmes to finance biotechnology were started in the late 1980s.

In this paper we investigate whether there are specific factors in competencies or institutions that could explain the uncertain situation regarding commercialisation of biotechnology in Finland. We seek to identify the major bottlenecks and challenges facing

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the commercialisation of biotechnology and use a comparative approach for our assessment, taking the Finnish success in Information and Communications Technology (ICT) as a benchmark. The most visible feature in the ICT sector in Finland is the emergence and growth of Nokia into a global telecommunications giant, although other firms in the Finnish ICT sector have been successful as well.

More specifically, the aim of this paper can be broken down into the following two research questions:

1. To what degree can we identify actors, functional competencies, and institutions of relevance to the successful development and commercialisation of biotechnology in Finland?
2. To what degree do the development and commercialisation possibilities of biotechnology differ from that of ICT in Finland in terms of these actors, functional competencies and institutions, and what might these differences imply for possibilities of achieving a biotechnology breakthrough in Finland?

This paper finds inspiration in the broader framework of life cycles of emerging technologies and industries and related institutional changes as outlined by Perez.[2] In order to understand the dynamics of the development and deployment of ICT and biotechnology, taking into account their different stages of maturity, we draw on Perez' concept of technological revolutions. We are aware that biotechnology is still in an early phase in its development and wider economic impacts are pending. The Finnish case may not deviate significantly from the examples of many other countries.[3]

Given the comparative nature of our approach, we will use the concept of 'competence bloc' as a way of systematising the case study comparison of the development of Finnish biotechnology set against the development of ICT in Finland. This concept is useful in this context as it identifies a set of actors, functional competences, and institutions that are necessary for the successful selection of emerging technologies.[4] This concept is especially useful for our purposes because it singles out critical analytical dimensions of the commercialisation of new technologies and the emergence of industries in general.

1.2. Limitations and Structure

Despite the relevance of analysing the case of modern biotechnology in comparison with the ICT success story in Finland, our comparative analysis has some limitations that the reader should take into account.

First, a major limitation relates to different dynamics that characterise the two industries as they are in different phases of maturity. Our analysis is mainly limited to developments in the 1990s due to data constraints, although we refer to the earlier history of both industries to a certain extent. If we wish to compare the two industries, ICT and biotechnology, in the same phase of development, we should compare present-day biotechnology with ICT in the 1970s or 1980s. We cannot compile, however, the required data in a systematic way from this time period. Therefore, our study is not a strict comparison of the two industries during the same development phase, but rather an exploration into potential bottlenecks in the Finnish biotechnology industry drawing upon the competence bloc approach and the example of the ICT sector.

Second, many of the developments in the Finnish ICT sector are related to Nokia's phenomenal rise to prominence. Thus the dynamic development of the industry is very

much dependent on the emergence of one major actor, even though the origins of Nokia can be traced back to a set of smaller firms and networks of inventors converging around digital and wireless technologies developed in the 1970s and 1980s. The prominence of Nokia implies that we analyse Finnish biotechnology developments set against quite an extreme benchmark. Nonetheless, this limitation can also be considered in a different light. In particular, we suggest that it enables us to highlight those aspects of biotechnology developments that have been problematic in Finland in so far as ICT represents a 'competence bloc' at its best.

Third, we focus on upstream actors, competencies and institutions (i.e. mainly non-market selection processes), implying that we explicitly ignore the various ways in which the different market structure and demand patterns of industries (market selection) influences their development further upstream. Thus we will not focus on, e.g. the role of customers in the development of the two industries, even though we are aware of their importance for commercialisation processes and of their central role in the competence bloc approach. An important reason for leaving these factors outside our empirical analysis, however, is the difficulty in collecting meaningful and systematic data on them.

The paper is structured as follows. Section 2 elaborates on the framework developed by Perez[5] to highlight how institutional pre-conditions for emerging industries matter for their development, as exemplified by the case of ICT. We then turn to the concept of a 'competence bloc' as a way of systematising the comparative case study. Section 3 starts with a discussion of the data we use in the comparative study. It then proceeds with the analysis of the emergence and development of modern biotechnology in Finland in comparison with the successful case of the ICT sector, along the lines suggested by the concept 'competence bloc'. Section 4 synthesises the main findings and concludes the paper.

2. A Conceptual and Analytical Framework

2.1. Technological Revolutions

Perez' book on the role of financial capital at the different stages of technological revolutions provides a macro-level dynamic and historical perspective on the way deep-seated technological changes are implemented and impact the economy and society. It draws attention to the role of various forms of capital—production capital and financial capital—in different phases of what she calls technological revolutions.[6] Her view can provide an overall perspective on our study and the different stages of maturity of the ICT and biotechnology industries.

According to Perez, a technological revolution is a 'powerful and highly visible cluster of new and dynamic technologies, products and industries, capable of bringing about an upheaval in the whole fabric of the economy and of propelling a long-term upsurge of development'.[7] Each technological revolution, of which there have been five so far, will cause profound institutional and organisational changes in the economy and in the whole societal infrastructure.

Technological revolutions start with a 'big bang', a breakthrough that shows that the new technology is cheap enough to make business based on the associated innovations cost-effective.[8] Perez defined four basic phases within each surge of development brought about by a new technological revolution: from an early irruption phase, when the new products and technologies are showing their future potential, through a frenzy phase with

an intensive build-up of a new infrastructure and new technologies, but with increasing structural tensions leading to structural and institutional changes in the system after a turning point. Last, the new technologies are deployed broadly in the system during a synergy phase ending in a maturity phase, where the last improvements of the technologies are introduced as investment opportunities start to dwindle and markets stagnate. In each phase, financial and production capital play a different role. The financial institutions may have to undergo radical reforms and adopt new practices to support the development and diffusion of each technological revolution. Thus, for example, we can maintain that venture capital is one of the institutional innovations that emerged in the frenzy period of the ICT revolution; financing the experimental developments in the new technology.

Currently we are in the midst of the fifth technological revolution; that of the Age of Information and Telecommunications, and in the beginning of the synergy phase after the turning point (see Figure 7). The ICT is thus just entering its wide deployment period. According to Perez, however, at the moment it is unsure whether biotechnology, together with bioelectronics and nanotechnology, will produce the next technological revolution, 'because the key breakthrough that would make it cheap to harness them is still unpredictable'. Biotechnology is thus still at a very early stage in its potential for a new technological revolution and has not yet had its 'big-bang' in Perez' sense; that is, a breakthrough that shows that the new technology is cheap enough to spur business based on the associated innovations' cost-competitiveness.[9] Thus the profit-making opportunities that will attract financial capital are still pending. This will be of importance when we interpret some of the findings of our study. Others have noted of late that the biotechnology industry is not living up to its potential, and blame this on a variety of factors, e.g. on the structure of industry adopted from the ICT.[10] Perez' approach provides an explanation of the matter from the point of view of long cycles of techno-economic developments.

Despite the different phases of development, in this context, an important similarity between ICT and biotechnology is their high R&D intensity and the generic nature of the underlying technologies. For both, institutionalised, systematic and goal-oriented R&D is of prime importance. Nonetheless, the sectors differ in many respects. Beyond size considerations, biotechnology and ICT have fundamental differences in the sources of technological opportunities[11] in particular, but also in other dimensions, some of them related to the concept of technological regimes.[12] One salient feature of modern biotechnology is its very close reliance on scientific research and breakthroughs, often emanating from university and government research.[13] By contrast, innovation in the ICT sector depends more on technological developments than on science *per se*, and on collaboration with customers in downstream product markets.[14] Furthermore, the product approval process in biotechnology is more heavily regulated and the overall product development in application areas such as drug discovery, is very long (even 10–15 years).

An important feature of the ICT sector is the fact that firms benefit from network externalities. Innovation and performance of firms essentially depend on how they manage to integrate their products with existing and future infrastructures and equipment.[15] In other words, innovation is highly systemic by nature and new markets are often created by firms themselves through standardisation of technologies and critical interfaces between them.

By contrast, in biotechnology the new innovative products are not systemic, but rather isolated, and for each new innovative product the markets have to be created. Some of the products are so new that they have no ready-made markets, while others, such as biomaterials, may replace existing products with superior qualifications. Still, even these cannot rely on network externalities through joint platforms and standards for a range of products.

We can conclude that the two areas are in different phases of development with biotechnology still being much less mature. According to Perez, biotechnology still lacks the decisive invention to qualify it as the foundation of a new technological revolution. By contrast, the ICT industry is in the deployment period of its technological revolution.[16] These different development stages have a consequence for our analysis of concurrent events.

2.2. Competence Bloc as an Analytical Tool

Apart from Perez, especially in the tradition of evolutionary economics, others have also started to emphasise the importance of institutional pre-conditions for growth and their differences across sectors and technology fields.[17] Eliasson and Eliasson introduce the concept of competence blocs as a possible framework for this kind of analysis that is particularly attractive for our purposes in this paper.[18]

The competence bloc is a set of functional circumstances that provide a selection mechanism and may be understood as a critical factor transforming technological opportunities into viable businesses. It is defined by a minimum set of activities, to be undertaken by competent actors in order that firms and industries emerge, develop and contribute to economic growth. It does not cover the supply side of technological innovations, but presumes that new technological ideas are being created, and concentrates on the market/dynamic demand side of the process whereby new technological ideas are turned into businesses spawning economic growth. In this paper, when referring to the supply side we will speak of technological opportunities and clusters of technologies from which inventions and innovations emerge.

The ultimate performance of a competence bloc, as defined above, is determined by the choices of customers in the market and the diffusion of technologies and innovations. Nonetheless, our focus in this paper on institutional pre-conditions further upstream (mainly non-market selection processes) within the broader framework developed by Perez[19] implies that we are primarily concerned with five remaining actors and functional competencies affecting the selection of technologies prior to commercialisation of emerging technologies on a grander scale. These five actors and related functional competences include:

1. *Inventors* who solve problems by integrating technologies in new ways through creative combinations;
2. *Entrepreneurs*, or innovators, who identify profitable inventions and introduce them in the market;
3. *Competent venture capitalists* who recognise and finance the entrepreneurs at a reasonable price;
4. *Exit markets* that facilitate ownership change and secure efficient turnover of venture capital funds in the economy; and
5. *Industrialists* who take successful innovations to industrial scale production.

The inventor represents the supply side in a competence bloc with the important task of creatively combining new and old technologies, thereby contributing to the generation of novel ideas. The task of the entrepreneur is to identify those ideas with the greatest potential commercial value and, therefore, to contribute to turning inventions into innovations on the market. In a competence bloc, the entrepreneur is thus also the innovator. Because the entrepreneur is also a bearer of the risks of failure, he will need funding by the venture capitalist to carry out his ideas.

The venture capitalist needs sufficient competences to identify the winning entrepreneurs and to provide reasonably priced equity funding. Furthermore, the ability of a competent venture capitalist to supply critical management expertise is important, especially at the early stage of a high-tech company.[20] In order to stay in business, venture capitalists need functioning exit markets to provide sufficient incentives to invest and therefore to secure a high investment turnover amongst new start-ups. Finally, Carlsson and Eliasson[21] emphasise the importance of the industrialist who takes the innovations of successfully selected entrepreneurs and turns these technological opportunities into global businesses.

3. Different Developments in the Finnish Biotechnology and ICT Industries

3.1. A Note on the Data Used

This paper provides a synthesis of a series of studies the authors have conducted, with colleagues at the Research Institute of the Finnish Economy, on both the ICT and biotechnology industries in Finland. Thus, for example, they have been involved in collecting a comprehensive, updated database on biotechnology firms in Finland and have conducted two consecutive surveys as well as interview-based studies with biotechnology firms. Statistics Finland has been unable to apply relevant criteria allowing it to provide adequate information on the biotechnology industry in Finland. By contrast, Statistics Finland has relevant and reliable information on the ICT industry and this has been reported. In each case, reference is made to previous publications reporting details of these studies. It should further be noted that the surveys with biotechnology firms have managed to obtain very high response rates (87–95%).[22]

The biotechnology and ICT sectors are in Finland, as in many other countries, very different in size. Currently, there are around 120 active biotechnology firms in Finland, 13 of which are older diversified firms that have expanded into modern biotechnology.[23] This definition takes into account firms that develop and apply modern biotechnology in assorted sectors of application, such as drug development, food and feed, other chemistry industries, agriculture and forestry, the environment, biomaterials, and diagnostics. It does not include medical devices. The industry in Finland is quite young, with the majority of the firms founded in the 1990s.

The ICT sector is significantly larger comprising nearly 9000 firms.[24] Here we define the ICT sector as comprising industries manufacturing office machinery, computers, transmission wires and cables, electronic components, and radio transmitters and receivers. We also include telecommunications and computer-related services. It should be noted, however, that traditional industry boundaries within the ICT sector are becoming blurred due to convergence between computing and telecommunication as a result of the digitalisation of the ICT infrastructure.[25]

3.2. Inventiveness

As mentioned above, the inventor represents the supply side in the competence bloc, filtering creative combinations of technologies through to the various other actors. This viewpoint on inventiveness is reminiscent of Schumpeter's discussion of 'creative combinations'.[26] He maintained that inventions are seldom radically new since they typically draw on technologies developed in the past. Sometimes the role of the inventor and the entrepreneur might coincide, with the latter turning inventions into profitable innovations. In biotechnology, this is a frequent phenomenon and often cited as a problem, because the innovators—typically researchers—often lack business acumen.

In the following, we assume that patent data capture inventiveness rather than innovativeness. We use Finnish patents granted by the US Patent Office (USPTO) in 1985–1999 to identify broader patterns of inventiveness in the two sectors. The data were taken from Jaffe and Trajtenberg.[27] Accordingly, we maintain the Schumpeterian distinction between inventors and innovators/entrepreneurs as is the case also in the framework of competence blocs. It should also be noted that US patents are more suitable in comparative studies, since the US market is one of the largest single markets for advanced products, such as ICT equipment and biopharmaceuticals.

On the basis of Figure 1 it is clear that the ICT sector by far outpaces the biotechnology industry in the number of patents granted. The reason is also self-evident. Nokia, the dominating firm in the ICT sector in Finland, accounts for a very large share (75%) of all patents granted to Finnish inventors by the USPTO during the period under investigation. This is also captured by other aggregated data such as R&D expenditures and export figures.[28] In the biotechnology industry, the concentration of patenting across specific firms is less pronounced, although 14% of all patents in the period examined were granted to the Orion

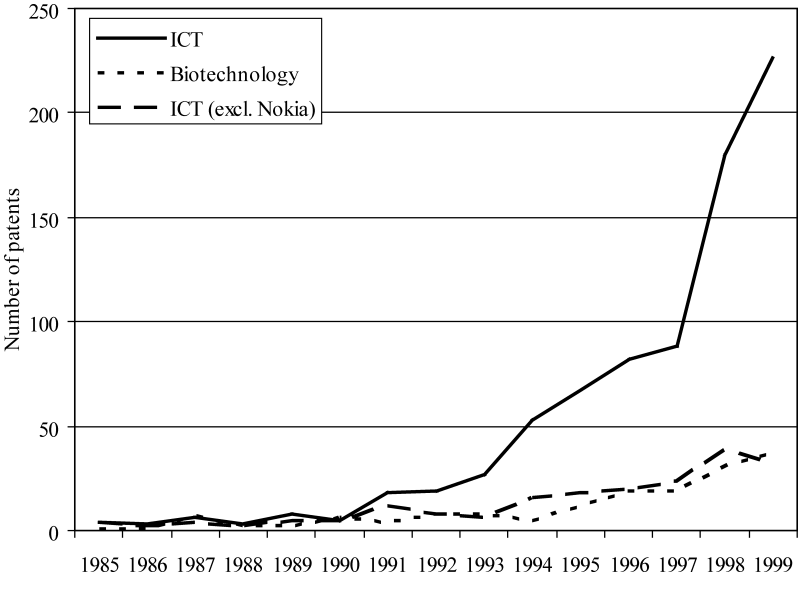

Figure 1. Patents with a Finnish inventor at the USPTO 1985–1999 compiled by year of grant (*Source*: USPTO and Jaffe and Trajtenberg, Ref. 27)

Corporation as the only remaining Finnish-owned firm involved in pharmaceuticals and related fields.

Because of Nokia's dominating position, Figure 1 gives ICT patents not held by Nokia. This allows us to compare patterns of inventiveness amongst the smaller inventors and entrepreneurial firms. The highly dominant position of Nokia in Finnish patenting in the ICT is highlighted by a comparison to Sweden (Appendix, Figure A1), which has a somewhat lower degree of concentration. In addition to Ericsson, Sweden's largest ICT firm, there are other large firms that patent in this field.

In the Finnish data with Nokia excluded, the biotechnology and ICT sectors seem to display relatively similar patterns over time. The rate of patenting remained at a relatively modest level throughout the 1980s, but it has picked up since the early 1990s. The level of patenting across the two sectors is relatively similar despite size differences and problems in defining biotechnology and ICT through patent classes.

Major national research programmes in the biotechnology field started in the late 1980s. Nevertheless, research funding did not display decisive growth until the 1990s, especially towards the end of the decade.[29] Patenting activities picked up in the late 1990s, probably reflecting funding in earlier years. We presume that the time from research to patentable inventions is longer in the biotechnology field than in ICT. Since public R&D funding in biotechnology has grown considerably in recent years, we may expect that the number of patents will grow further in the future.

Taking the respective sizes of the two sectors into account (i.e. by excluding Nokia), patenting is deemed more frequent in biotechnology than in the ICT sector. This may reflect the fact that patenting is probably more important in biotechnology than in the ICT sector. Because of the length of the innovation process in biotechnology, securing the intellectual property rights by patenting becomes a pre-requisite for investing in the field. At the firm level, patents also serve as a sign for investors about the potential economic value of a company, thus reinforcing the importance of patenting.[30]

3.3. Entrepreneurship

Entrepreneurship is difficult to measure because of problems related to its definition and the availability of data. Firm entries and exits, changes in the size distribution of firms, the number of market participants, and the number of self employed business owners in an industry have all been used as proxies for entrepreneurship.[31] We will use the share of entrants of all firms, and its share over time, as a rough proxy. This is compatible with the framework employed in this paper, namely that entrepreneurs are the actors who identify inventions with economically promising potential and take them further into a business setting by establishing a new firm. Entrepreneurs thus bear the risk of failure in competition. For the sake of comparison, we also include entry ratios for Finnish industries as a whole.

The time period covered by Figure 2 coincides with Finland's relatively rapid recovery from the deep recession of the early 1990s. This period coincides with the most rapid growth of both the ICT and biotechnology sectors in Finland. Some interesting and divergent patterns in entrepreneurship are nonetheless clearly visible.

By and large, entrepreneurship as reflected in firm entries has been more dynamic in the ICT sector than in biotechnology and other industries, though relatively, biotechnology is not lagging very far behind. There are, however, large fluctuations in the new entrants in biotechnology, which reflects the fact that the overall number of firms has been small.

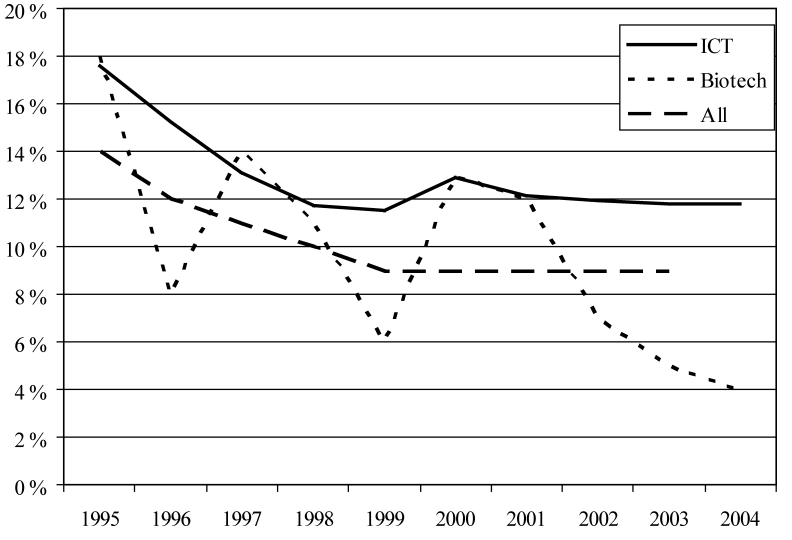

Figure 2. Entry ratios in biotechnology, ICT and all other industries in Finland 1995–2001 (*Sources*: For ICT, Statistics Finland; for biotechnology, ETLA and Etlatieto Ltd database on Finnish biotechnology firms)

Barriers to starting enterprises are higher in biotechnology than in the ICT sector, because of requirements with regard to, e.g. instrumentation, laboratory environment (sterile facilities), and stringent regulation, which is reflected in high R&D costs. Public authorities have promoted the establishment of biotechnology enterprises by building laboratory spaces and business facilities in so-called bio-centres, founded in conjunction with major universities engaged in the biosciences. In the past two years, however, new biotechnology firms have been established much less frequently.

With regard to the ICT sector, there are several interpretations and underlying factors that help to account for the observed developments. First and foremost, we again have the Nokia effect at work. Nokia has been an important promoter of entrepreneurship through spillovers and its role as a collaborative partner. Ali-Yrkkö[32] notes that in 1998 some 100 firms in the ICT sector were first-tier subcontractors to Nokia in the various fields of R&D services and software, component manufacturing, and electronic manufacturing services. Most of these firms were small with a median number of employees—slightly over 30.

The higher entry ratios of entrepreneurship in the ICT sector can also be related to the general boom and high expectations that have characterised these technologies, especially in the latter part of the 1990s, prior to the burst of the bubble.[33] This so-called 'ICT hype' was largely related to developments in internet technology and e-commerce, where entry barriers were lowered significantly, leading to a serious backlash.[34] This is supported by the finding that the highest entry and exit ratios within the ICT are in services, and in particular, in telecom and computer services.[35]

Firm dynamics in biotechnology is, however, very low with respect to firm exits, which have picked up only in very recent years (Figure 3). Firm exits or deaths are important in weeding out unsuccessful projects. Overall, the exit rate of new firms in all sectors is very high (15% during the first year in all fields in Finland).[36] The very low exit rate in

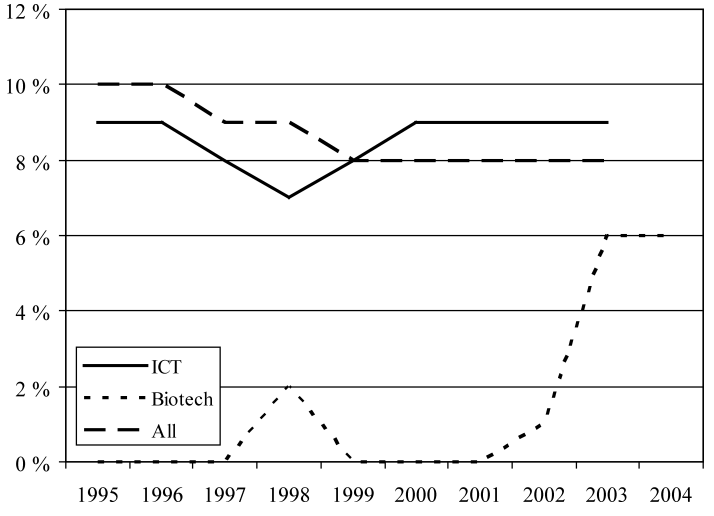

Figure 3. Firm exists in ICT, biotechnology and all fields (*Sources*: For the ICT and all sectors, Statistics Finland; for biotechnology, ETLA database on Finnish biotechnology firms)

biotechnology is indicative of a lack of dynamics in entrepreneurship as well as the fact that entrepreneurship is different in biotechnology: firms are often 'R&D projects' supported by various public programmes.

3.4. Venture Capital Market

3.4.1. Role of venture capital in a competence bloc

Eliasson[37] regards the venture capitalist as the key actor in a competence bloc for any country ensuring an appropriate incentive structure for entrepreneurship. Perez[38] argues for the high probability of incumbent production capital (firms) to be conservative when faced with radical technological change. The incumbent firms have their existing interests to defend. Thus, there is a need for the emergence of financial capital and new financial institutions to foster the rise of the new entrepreneurs.[39] Eliasson[40] is sceptical about the success of big established firms as venture capitalists since these incumbents tend to be conservative and lack the competence to evaluate exceptional new technologies.

The government is not competent enough either to evaluate, and thus finance, really new commercially relevant technologies.[41] Provided there is a sufficient number of private venture capitalists (VCs) constituting a viable VC industry, 'en masse' they will have capabilities to choose winning projects and compete with each other for investment targets thus securing reasonably priced investments. They also have incentives to provide their portfolio companies with non-capital assistance, that is, value-adding capabilities in management, headhunting, marketing, and networking, as well as certification and reputation.[42]

3.4.2. Venture capital investments

The liberalisation of the financial markets in the late 1980s, their collapse in the mid 1990s, and rapid economic growth since then have paved the way for the emergence of a more developed VC industry in Finland. Traditionally Finnish financial markets were highly

bank-centred until the mid 1990s.[43] The increasing size and liquidity of the Helsinki Stock Exchange has stimulated the entry of private sector venture capitalists, providing them with an expanding exit market. Private sector venture capital firms invested close to 95% of all available equity in 2002, compared to 51% in 1991.[44]

Finland has a dual VC system: a rapidly developed system of private, independent VCs and a few strong public sector VCs. Corporate VC activity is limited. In addition, there is business angel activity the size of which is, however, difficult to estimate.

As depicted in Figure 4, the emergence of the VC industry in Finland is captured in the increase in the number and total volume of investments annually. Investment volumes increased significantly, especially in the late 1990s. Some of the private VC managing companies are specialised in the ICT sector, while maybe only one is specialised in the biotechnology sector, but is investing in other areas too.

To be able to compare biotechnology and ICT, average investments per financing decision are here taken as a rough indicator of the degree of risk that the venture capitalists have been willing to bear. They do not, unfortunately, capture the 'competence-intensity' of these investments; that is, how insightful they have been.[45] Figure 5 displays trends in these averages and includes all other industries for purposes of comparison, though in fields other than ICT and Life Sciences, investments are oriented primarily toward later stages and are generally larger than investments at the early stage; more often a characteristic of Life Sciences and ICT.[46]

Average annual investments in the ICT and Life Sciences sectors were fairly even and decreased after the bubble. In the ICT sector, the average size peaked in 2000, while in Life Sciences the all-time-high was reached a year later. The adverse effect of the ICT hype is visible in the decreasing trend in both sectors. According to Antila,[47] venture capitalists have

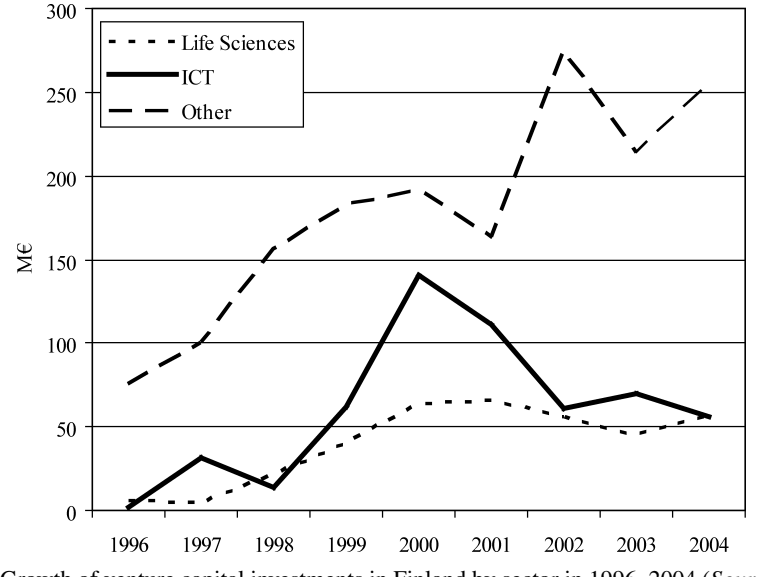

Figure 4. Growth of venture capital investments in Finland by sector in 1996–2004 (*Source*: Finnish Venture Capital Association)

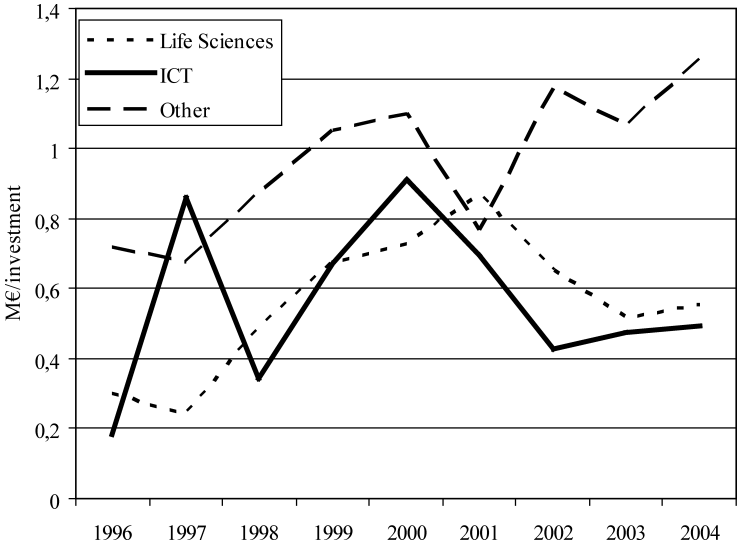

Figure 5. Average VC investments in Life Sciences and ICT in 1996–2004 (*Source*: Finnish Venture Capital Association. *Note*: FVCA uses the term Life Sciences, which roughly corresponds to the field of biotechnology, though it is presumably broader)

grown increasingly risk-adverse and short-sighted; short-run profits seem to be crowding out longer-term patient funding.

The above findings indicate that, in general, VC investments in biotechnology are at a reasonable level, though probably insufficient for the needs of the firms. This conclusion is supported by a recent study on VC activity in biotechnology by one of the authors of this paper.[48] The study showed that in total, 56% of the dedicated SMEs in biotechnology established since 1986 had received VC funding, and 44% of those without VC funding (and 20% of all firms) had failed to obtain it. This study further indicated that there are three major actors in VC funding in this field: business angels, public sector VC organisations (Sitra, the Finnish National Fund for Research and Development, being the most active in biotechnology) and private-sector VCs. Each of these invests in different stages of a firm's life with business angels investing in the youngest firms and the private-sector VCs in oldest firms (*ibid*.). There are also a few foreign VCs investing in this field.

In view of these positive findings, there are, nonetheless, two major problems. First, biotechnology start-ups find difficulties in attracting more private VC funds because they do not mature quickly enough to be suitable investment targets for venture capital business logic. Second, the major public-sector VC financier, Sitra, has declared its intention to withdraw from the biotechnology sector leaving a gap in the funding sequence of firms. Although complementary sources of public funds, such as R&D loans and subsidies, especially from the National Technology Agency of Finland (Tekes), are important for new biotechnology firms,[49] they cannot provide a substitute for VC funding.

3.4.3. Exit markets

The possibilities for the venture capitalists to reap the returns on their investments are of crucial importance for the overall dynamics of the VC industry and the market for VC

funding. Exits represent the final stage of the venture capital cycle, but they also mark the start of a new cycle by providing liquidity and thus contribute to further fundraising.[50] Major routes through which venture capitalists may exit their investments include (i) a trade sale or the sale of a portfolio company to another (including mergers and acquisitions or M&As), (ii) an initial public offering (IPO) of the firm's shares, (iii) management buy-outs, or if none of these are possible and the investment turns out to be unsuccessful, (iv) the investor has to write-off the investment as a loss.[51]

Stock trading emerged as an alternative exit route following financial market liberalisation in the late 1980s. Nonetheless, the Finnish stock market is still small as measured by the share of market capitalisation when compared with other European stock markets, especially when the effect of Nokia is controlled for. Likewise, the liquidity (turnover of stocks) of the market is poor and largely concentrated on a few larger firms. Finally, the market has been comparatively volatile in terms of stock prices. This implies that the environment for public offerings is uncertain and has hampered the planning and correct timing of VC exits. Therefore, mergers and acquisitions have provided an alternative to public offerings.[52]

Public offerings have been a practically non-existent exit route especially in biotechnology. Aside from large multi-technology firms that have expanded their activities to biotechnology, only three biotechnology firms have been listed on the Helsinki Stock Exchange, one in New York (this firm is no longer a separate firm but has been sold to a larger company) and two in London. A major exit possibility is a trade sale to another domestic firm or a foreign firm. The former most often means mergers of two or more small biotechnology firms, while the latter means a sale of the Finnish company to a big foreign firm, or in some cases, to a new firm founded in, e.g. the USA for the sake of commercialisation, manufacturing and marketing of the innovation. Exits through trade sale are clearly increasing.[53] So far, there have only been a few bankruptcies, as illustrated by Figure 6, which depicts the number of mergers and bankruptcies in biotechnology since 1990.

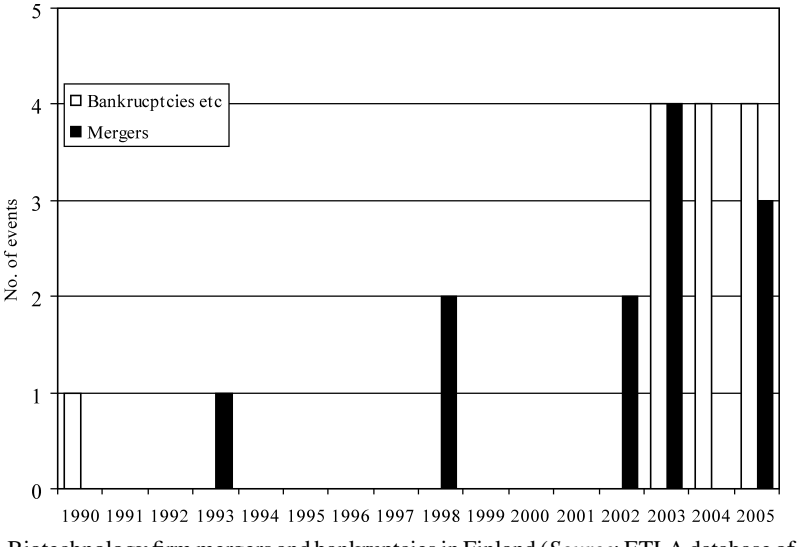

Figure 6. Biotechnology firm mergers and bankruptcies in Finland (*Source*: ETLA database of Finnish biotechnology firms)

Developments in the ICT sector have clearly been different, because the sector has witnessed far more public offerings, especially in the early 2000s. According to Rönkkö[54] Finnish VC-related entrepreneurs have been relatively more technology-driven and focused on 'hard patentable technologies' compared to the situation in Sweden, for example, where many new firms were so-called dot.coms without notable proprietary technologies. Moreover, a few owners of listed ICT firms have entered the venture capital industry, helped by resources raised through IPOs and the experience that these individuals have gained in the relevant industry. Furthermore, the share of foreign venture capitalists is higher in the ICT sector than in the biotechnology industry.[55]

3.5. From Innovations to Large-scale Production

The industrialist should step in, at the very latest, when innovations approach the phase of commercialisation, marketing and large-scale production. The industrialist should thus possess what Eliasson and Eliasson[56] refer to as 'industrial competences'. According to Teece's analysis,[57] it is a question of complementary assets that industrialists provide. The industrialist has a pivotal role to play in the competence bloc because these competences link the activities of inventors and entrepreneurs with the growth of industries, and eventually the whole economy. Large-scale industries do not emerge if the industrialist is absent or incompetent in the competence bloc.

In the biotechnology sector, there have been no major industrialists or networks of firms creating complementary assets for each other. Some older firms in various application sectors, such as food (Valio), enzymes (Alko) and pharmaceuticals (Orion Pharma) had development projects in new biotechnology, but in the early 1990s shed a major part of these activities. This gave rise to new biotechnology start-ups, which have developed their innovations further and obtained the respective intellectual property rights. In pharmaceuticals, perhaps the most important application segment of biotechnology, there is only one major domestic firm (Orion Pharma). It is nonetheless small by international comparison and focused on a limited range of therapy areas. It seems that small biotechnology firms have to seek industrialists abroad and are actively doing so at present.[58]

In drug discovery, firms develop their products to clinical phase I (or II) and license out the intellectual property rights to a large pharmaceutical firm for further development, manufacturing and marketing of the product. Firms in application segments outside the drug discovery have a vertically integrated organisation and wish to bring their innovations to an industrial scale. However, in most cases, they aim at niche markets and do not plan to manufacture on a larger scale.[59]

By contrast, the ICT sector provides a range of examples of the role played by industrialists at various phases of its evolution. For example, in the 1980s the Finnish public telecom operator (PTO),[60] served the dual role of industrialist and sophisticated customer: it was a competent service provider, and via its procurement decisions, it encouraged Nokia (Nokia's predecessor firms) to deliver the required equipment on a larger scale and realised the business opportunities of mobile telephony.[61] This took place during the birth of the Nordic Mobile Telecom (NMT) standard. Collaboration between the PTO and Nokia continued throughout the 1980s and 1990s and extended to the marketing of Nokia's systems in connection with the inauguration of NMT networks throughout the world. By the time GSM was standardised, however, Nokia emerged as the industrialist in the Finnish ICT

sector by pulling along other smaller subcontracting firms towards large-scale production and commercialisation in various fields.[62]

4. Concluding Discussion

4.1. Major Differences between the Development Paths of Biotechnology and ICT

Table 1 summarises the findings of a comparison of biotechnology with the ICT sector in terms of the nature of their competence blocs.

The results point to quite significant differences in the composition and completeness of the competence blocs in the Finnish biotechnology and ICT sectors. With regard to the success of the ICT sector, we can conclude that many of the critical dimensions of the competence bloc have been in place, especially in the 1990s, although some weak spots and new challenges are becoming evident. By contrast, the performance of the biotechnology industry has been much weaker as there have not yet been any major commercial successes; most firms are still in the product development phase, and new biotechnology firms are still very small. Likewise, there are clear indications that the related competence bloc is still nascent in many important ways.

Overall levels of *inventiveness* in the biotechnology sector do not differ as much from the ICT sector as one might perhaps expect, given the late growth of patenting and the young age of firms within modern biotechnology.[63] When we filter out Nokia from the data, the overall level of patenting in biotechnology is by and large on par with that of the ICT sector. The relatively high level of patenting suggests that there are strengths in biotechnology-related scientific and technological fields. Hence, we suggest that the major challenges of the Finnish biotechnology sector do not seem to relate to inventiveness as such.

Table 1. Nature of competence blocs in the Finnish biotechnology and ICT sectors

Analytical dimension	Biotechnology	ICT
(1) Inventiveness	• Late start, increasing • Widely distributed, no special focal point	• Early start, increasing • Dominance of Nokia and associated firms
(2) Entrepreneurship	• Around average • Fluctuating	• Above average • Even trend, decline since the early 2000s after 'ICT hype'
(3) Venture capitalists	• Average investments close to those in the ICT, adverse effects of 'ICT hype' • Fewer and less specialised VCs	• Rapid growth of investments until 2000; and equally rapid decline since 'ICT hype' • More (competent) VCs, also foreign
(4) Exit markets	• Very few VC-related IPOs, trade sales as major route	• Relatively many more VC-related IPOs
(5) Industrialists	• Shortage of incumbent firms taking the role of industrialist in core biotechnology fields • Commercialisation paths sought abroad	• Previous role of PTO, Nokia as prime industrialist in the 1990s

When turning to issues of *entrepreneurship*, developments in the biotechnology sector are less positive. Despite measurement problems related to capturing entrepreneurship, we conclude that entry shares in the biotechnology industry have been somewhat lower than in the ICT sector, and there is a sharp decline in the past few years. We also suggested that biotechnology is relatively more disadvantaged when compared to the ICT sector as a result of the high entry barriers posed, for example, by costly instrumentation and laboratory spaces as well as the strict regulations related to clinical trials of many biotechnology products that prolong their development cycles. In contrast, the ICT sector has benefited from the systemic nature of innovation and the emergence of Nokia, whereby a significant number of firms have entered the sector in collaboration with Nokia. The systemic nature of innovation is to some extent also a reflection of the more mature stage in its techno-economic paradigmatic development, which brings about more abundant opportunities for applications in a wide range of areas.

Our analysis suggests that overall *venture capital funding* in the biotechnology sector in Finland is probably at a lower level than large-scale commercialisation would need, especially when taking into account the high barriers to entry in terms of the investments required. Despite overall positive developments, the VC industry specialised in biotechnology is still undeveloped and can be one of the bottlenecks for the further development of the biotechnology sector. The ICT hype and subsequent downturn has crowded out venture capital financing from the biotechnology sector, as venture capitalists have become more risk-averse and more conservative with respect to longer-term investment with uncertain profits. Exit possibilities for VCs that have invested in biotechnology, especially through public offerings, have been limited. A notable exit route for the venture capitalists is a trade sale, of which there have not yet been many, but there will probably be more in the future. The fact that the major public-sector VC financier, Sitra, is withdrawing from biotechnology area, leaves a gap in VC funding.

The major bottlenecks and challenges facing the application of modern biotechnology in Finland, however, relate to the lack of *industrialists* capable of turning innovations into large-scale production for the global market. Industrialists provide an innovating firm with complementary assets.[64] These assets may vary a great deal from sector to sector and even from firm to firm. Still, overall in biotechnology, industrialists provide the small innovating biotechnology firm with complementary assets that are needed in product development and product approval, in building manufacturing facilities and processes, and often in marketing. Major industrialists are so far lacking in Finland in relevant application sectors. It is conceivable that in the future, traditional industrial strengths such as forest or process industry will take biotechnology inventions to industrial-scale production in their own processes, but that is yet to be seen.

By contrast, in the ICT sector we claim that Nokia has not only enjoyed its role as inventor and entrepreneur during the early stages of its development, but has also taken the role of industrialist, especially during the critical phases of commercialisation of GSM-related digital technologies (even though we can also identify other industrialists, such as PTO in the 1980s). It is presumable that in ICT, the role of an industrialist differs from that in biotechnology, and is more related to the provision of network assets.

Teece's analysis of complementary assets was developed for the firm level. Nevertheless, he did draw conclusions at the national level when highlighting 'the importance to innovating nations of maintaining competence and competitiveness in the assets which complement technological innovation, manufacturing being a case in point'.[65] Without involvement in

large-scale manufacturing and marketing in biotechnology, which is at an early stage in its industrial development, Finland may not be able to reap sufficient returns to its investments in biotechnology R&D. Thus if industrialists are not located in the country, small innovating firms will have to cede a large portion of the profits derived from the innovations to firms in other countries. This is an essential problem for the future of Finnish biotechnology industry.

4.2. Sectors Set in the Perspective of Stages in Technological Revolutions

Seen from Perez' perspective, it is not surprising that, as noted in the analysis of this paper, VC investments in Finland are not abundant in biotechnology. Likewise, the utilisation of biotechnology in large-scale industrial production is still a phenomenon more of the future than of the present. The lack of industrialists may be partly related to a lack of profitable opportunities and we may presume that if/when biotechnology makes a breakthrough in terms of creating a foundation for a new technological revolution, industrialists will emerge.

Eliasson and Eliasson's competence bloc approach suggests a set of functional competencies for the commercial application of evolving new technologies. Their analysis is static in the sense that it is not set against a background of the life-cycle of deep-seated technological changes. We wish to bring in the perspective offered by Perez' analysis in order to highlight that each of Eliasson & Eliasson's actors and functional competencies appear at different stages in a technological revolution (see Figure 7). While all the functional competencies are important in the later, deployment period, they emerge at different stages in the revolutionary cycle: the role of the VCs starts fairly early on in the irruption phase, while industrialists step along in the phase of a wider application of the new technology, and inventors and entrepreneurs are needed in each phase. Though we may in theory presume that the functional competencies occur in this order, historically, the development

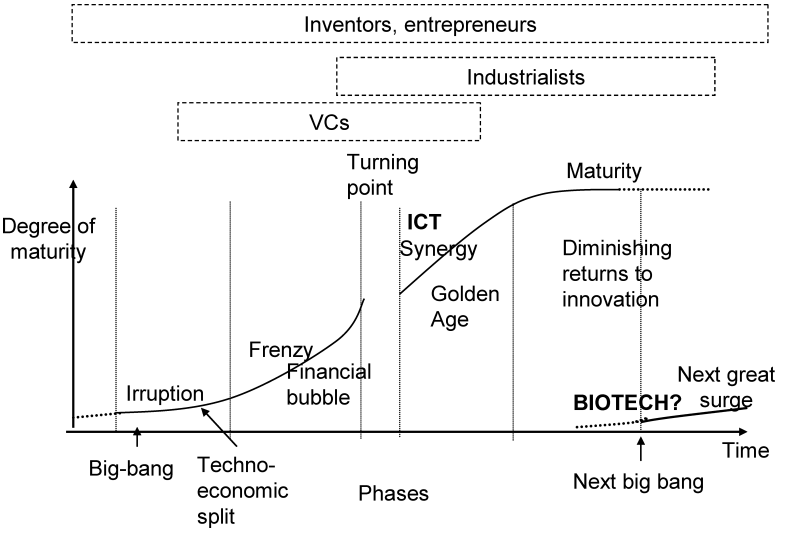

Figure 7. Functional competencies applied to Perez' curve of the phases of technological revolutions, and biotechnology and ICT positioned in their respective development phases (source for Perez' curve: Perez, Ref. 2)

of the functional competencies in the Finnish ICT competence bloc has not fully followed this pattern, particularly for the VC markets, which in general emerged in the 1980s. As mentioned above, in such a case there may be functional equivalents to the constituent parts of the competence bloc.

The evolution of a competence bloc entails co-evolution: functional competencies emerge to support commercialisation when the technology has proved viable. New competencies embodied in actors and institutions emerge as a response to the promises and rapid diffusion of the new technology. This is not, however, a deterministic process. In their analysis of the development of venture capital industries in Israel and the USA, Avnimelech *et al.*[66] have emphasised that this process is marked by co-evolution at different levels: at the level of technology, but also at the level of individual actors. There is a co-evolution process between venture capitalists and start-ups, namely that start-ups and venture capital firms need to develop some common understanding of goals, knowledge and capabilities for the former to accept a market for corporate control. It is also a question of co-evolution between the development of the VC industry and government actions to provide framework conditions, the funding of R&D, and the promotion of the VC industry.

There is a further important aspect to be noted. Pisano has of late noted that an important reason for biotechnology not delivering on its promise is the flawed industrial structure, borrowed from Silicon Valley and ICT.[67] The model of independent start-ups commercialising science-based discoveries has not worked in biotechnology as it has in ICT, and the industry would need new patterns of organisation, collaboration and sharing of know-how to succeed in turning science into business. It is thus a question of creating new institutional forms of entrepreneurship in order to better answer to the needs of this area. We can even claim that the Silicon Valley model of VCs does not work well in biotechnology because the expectations of VCs to be able to exit within 3–5 years are not feasible in biotechnology, where in many application segments, drug discovery and development in particular, the time periods required for product development span some 10–12 years.

Set against Perez' model of the phases of technological revolutions, we may observe that if and when biotechnology has its 'big bang', we may expect emergence of new financing arrangements and entrepreneurship models and institutions better suited to the needs of this area. However, even if there is no big bang, biotechnology can be an important enabling technology and help exploit ICT or other technologies more effectively. Its effective utilisation would in any case require learning from failures and adapting institutions to better harness this science-based segment for profitable business activity.

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nearly a €1 billion. As a comparison, gross domestic R&D expenditure in Finland was €5.5 billion in 2004. See T. Luukkonen & C. Palmberg, Suomen teollisuuden seuraava läpimurto? Uuden biotekniikan vertailu tietotekniikka-alaan, in: T. Luukkonen (Ed.) *Biotekniikka—tietoon perustuvaa liiketoimintaa* (Helsinki, Taloustieto, 2004).

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Appendix

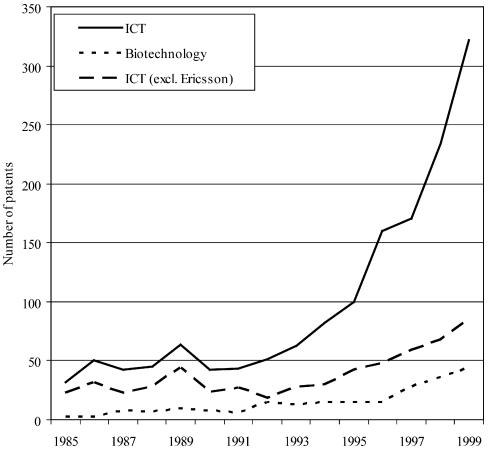

Figure A1. Patents with a Swedish inventor at the USPTO 1985–1999 compiled by year of grant (*Source*: USPTO and Jaffe and Trajtenberg, Ref. 27)