V A T T E T L A

INNOVATION SYSTEMS AND COMPETITIVENESS

OSMO KUUSI (Ed.)

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The technological change, with its pervasive influence in the economy and society, relates e.g. to techno-economic globalization, irreversible ecological damages and high unemployment. Finland like many other developed country has moved to an internationalized innovation based economy. The economic analysis of innovation based economies needs different concepts and tools than the analysis of factor-driven economies. The focus of this book is in these new concepts and tools. There are few ready answers to be given. The new conceptual framework of evolutionary economics, extensively discussed in the book, is still evolving. Many articles in the book seek theoretical or empirical content to the concept of national innovation system, which is aimed to substitute the traditional concept of "national competitiveness". The last articles of the book discuss about the possibilities of technology foresight. How to reason from already made inventions, innovations and production decisions and from realized and potential market demands possible new innovations?
Most of the articles in this volume were originally presented at a conference in Helsinki on 26th and 27th October 1995.
KEY WORDS: Growth, Evolution, Technology Policy, National Innovation System, Technology Foresight, Industrial Policies

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Monet taloutemme keskeiset ongelmat kuten teknis-taloudellinen globalisoituminen, ekologiset ongelmat sekä korkea työttömyys liittyvät teknologiseen muutokseen. Suomi on muutamassa vuosikymmenessä siirtynyt edullisiin raaka-aineisiin nojaavasta taloudesta kansainvälistyneeksi innovaatioista vahvuutensa hakevaksi taloudeksi. Innovointiin perustuvan talouden analyysi edellyttää uusia käsitteitä ja välineitä. Kirja keskittyy niiden pohdintaan, mutta ei tarjoa valmiita vastauksia. Evolutionaarinen taloustiede, jonka mahdollisuuksia pohditaan monessa artikkelissa, on vasta muotoutumisvaiheessa. Kirjassa tarkastellaan monelta kannalta sekä empiirisesti että teoreettisesti "kansallisen innovaatiojärjestelmän" käsitettä. Kirjan viimeiset artikkelit pohtivat teknologian kehityksen ennakoinnin mahdollisuuksia kuten tapoja, joilla asiantuntijatietoa käyttäen voidaan päätellä jo tehdyistä keksinnöistä, innovaatioista ja tuotantopäätöksistä sekä kysynnästä uusia tulevaisuuden innovaatioita.
Useimmat kirjan artikkeleista pohjautuvat Helsingissä 26.-27.10.1995 pidettyyn kansainväliseen teknologiaseminaariin.
ASIASANAT: Kasvu, evoluutio, teknologiapolitiikka, kansallinen innovaatiojärjestelmä, teknologian ennakointi, teollisuuspolitiikka.

PREFACE

Since the mid-1970s, the Finnish industrial structure has been rapidly moving from factor-driven towards technology-driven industries. At the same time, the knowledge intensity within the traditional strong clusters (forest and base metal) has increased through diversification to new product areas and upgrading of production processes. The increase in technology intensity coincides with the rapid internationalization of the firms which started to accelerate in the early 1980s.

Finland has become an internationalized, innovation based economy. Innovations and their commercial exploitation ultimately determine the success of enterprises in this type of economy. A prerequisite is the accumulation of sufficient human and physical capital as well as the knowledge base they create. Innovative activities always entail high fixed costs and big risks. In order to recoup these costs there is a need to tap extensive international markets, which also serves as a way of testing the strengths of the innovations. A key question for public policy in this type of economy is creating an attractive business environment: high quality infrastructure, competitive markets, stable macro economic conditions, good technological infrastructure and skilled labor.

The economic analysis of innovation based economies needs different concepts and tools than the analysis of factor-driven economies. The focus of this book is on these new concepts and tools. There are few ready answers to be given. The new conceptual framework of e.g. evolutionary economics is still evolving. The concept of the national innovation system, which is aimed to replace the traditional concept of "national competitiveness", is still seeking its exact content.

Most of the papers in this volume were presented at the Conference on "Innovation, Competitiveness and Technological Change" in Helsinki on 26th and 27th October 1995. The seminar was organized jointly by three Finnish organizations: VATT - Government Institute for Economic Research, ETLA - The Research Institute of Finnish Economy and VTT - the Technical Research Centre of Finland.

The conference and this book are foremost a common effort of the network of Finnish economists and sociologists concerned with technology studies. We are grateful to all lecturers, commentators and participants of the conference. It has been a pleasure to be a part of this network. The conference continued the tradition of two earlier technology seminars in 1991 and 1993[1].

The book is edited by Osmo Kuusi. We would like to express our thanks to him and to Torsti Loikkanen who assisted him in the editing work. We are also grateful to Helinä Silén for word processing work and to John Rogers for checking and improving the language of many articles.

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[1] The contributions of earlier seminars have been collected in two books: Vuori, S. and in Ylä-Anttila P. (eds) 1992, Mastering Technology Diffusion - The Finnish Experience, ETLA; and Vuori, S. and Vuorinen, P. (eds) 1994 Explaining Technical Change in a Small Country, Physica-Verlag in Association with ETLA.

CONTENTS

Page

IN SEARCH FOR NEW APPROACHES IN TECHNOLOGICAL CHANGE

Osmo Kuusi*, Torsti Loikkanen**

Growth Economics and Endogenous Technological Change

Several well-known national and global economy related problems have given impetus to economists to search for new paradigms in growth economics: Techno-economic globalization, irreversible ecological damages of global dimensions, high unemployment and related social problems in the developed world, unemployment, hunger and poverty in parts of the developing world.

Technological change, with its pervasive influence on the economy and society, relates to most of the problems mentioned above. Consequently, the capability of theory to illuminate empirical issues depends heavily on its capability to cope with technolocigal change. In the pioneer work of Schumpeter (1939), innovation was a central endogenous driving force for company´s profit, but in many later economic models technology is treated, to use Rosenberg´s words, as a ´black box´, as an exogenous variable.

Solow´s study in the 1950s illuminated the potential of technology in economic growth (Solow 1957). The study was based on the aggregate production function and it showed that as much as 87 per cent of the observed increase in labour productivity was due to technical progress. Since then, numerous efforts with the production function and other econometric models have been carried out in order to measure the importance of technological change and R&D to growth in the United States and other countries (see e.g. Mairesse and Sassenou 1991).

Since the mid 1970s, the research in this field was geared around the "productivity paradox" - the observed slowdown in productivity growth. The slowdown of productivity was an obvious paradox because technological developments, particularly the new information and communication technologies, did not seem to contribute to a satisfactory degree to growth in economic and social standards (see e.g. Technology in...1991). Numerous economic analyses, in the traditions of standard economics as well as institutional and evolutionary economics, were published in order to examine and illustrate the links and causalities of technological change on micro, macro and meso levels of the economy. This extensive work was presented and summarized in the OECD conference on Science, Technology and Economic Growth in 1989 (within the Technology/Economy Programme of the OECD, TEP).

* Government Institute for Economic Research; ** VTT, Technical Research Centre of Finland, Executive Staff.

All these efforts have improved our undestanding of the role and effects of technological change in the economy. Nevertheless, they have also given proof of the limitations of the economic measurement of technological change. Despite encouraging efforts within different research traditions, the involvement of technology as an endogenous factor in models remains a challenge. For example, in the Keynesian tradition, based *inter alia* on Kaldor's work, the vintage approach is developed in order to introduce annually invested technological progress, embodied in capital, into the model. Endogenous technological change is an essential idiosyncrasy of the "new growth models" of *inter alia* Romer (e.g. 1991), Grossman and Helpman (e.g. 1990), and Kanniainen (1994). The approaches, nourished by evolutionary and institutional thinking, such as the national system of innovation approach, or that of industrial cluster analysis, pursue to broaden the scope from standard approaches to technology-related angles by incorporating into the analysis the variables with less emphasis in traditional analysis (such as organizational changes, interactive learning, cumulative knowledge, vertical and horizontal cooperation of companies and other actors of innovation process). In these analyses technological change is the essential endogenized variable.

The Finnish research into technological change in economics has progressed increasingly in the spirit of the new growth models. To mention a few examples, the Research Institute of the Finnish Economy (ETLA) has followed the tradition of econometric analysis on R&D and productivity (e.g. Vuori 1991, 1992)[1]. The FMS-model of the economics department of Oulu University is an example of a vintage approach in the Post-Keynesian spirit (Mäenpää 1984). Theoretical work have been carried out, for example, by Kanniainen (1994) and Saarenheimo (1994).

Characteristics of Evolutionary Economics of Technological Change

A common emphasis of the economists influenced by evolutionary and institutional approaches is to move to **the dynamic and systemic economic analysis**. An important manifestation of the systemic approach is the Maastrich Memorandum of 1993. This study emphasizes the role of learning, the process of assimilation of knowledge, as well as the absortive capacity of firm. According to the Memorandum, the interest in the systems approach grew in the 1980s *inter alia* as a response to studies considering the organisation of innovation in successful firms[2]. As the Memorandum stresses, the systems approach emphasizes the role of **cumulative creation of knowledge** through learning in technical change, the importance of the

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1 Prof. Olavi Niitamo, the previous Director General of Statistics Finland, was one of the pioneers in studying the macroeconomic effects of education with the production function (see Niitamo 1958).

2 As an example the SIN model of Roy Rothwell is given. The ingredients of the SIN model are integrated parallel development, the use of expert systems and simulation modeling, linkages with leading edge customers, strategic integration with primary suppliers, horizontal linkages (e.g. joint ventures, collaborative research), emphasis on corporate flexibility and speed of development, increased focus on quality and other non-price factors. "SIN represents a model of the future in which *conceptualization leads practice.* Leading innovative companies are already introducing the elements of the fifth generation model into their innovative practice" (Rothwell 1992, 237).

assimilation process, as well as the *absorptive* capacity of a firm and the importance of diffusion of knowledge.

The **role of institutions** is often underestimated or even neglected in standard economic analysis. For example, Freeman and Perez (1988) argue that there are strong links between the technological (and economic) paradigm and the institutional setting in society. They refer to institutions, such as education and schooling systems, labour relations, politics and legal issues. Dosi defines institutions, first, as normal organisations, ranging from voluntary associations to state agencies, and then, broader, particular sets of norms which are socially shared, to different degrees socially enforced, and tend to inertially reproduce over time (1991, 358). In a parallel vein Hodgson stresses that institutions are social organizations which, through the operation of tradition, custom or legal constraint, tend to create durable and routinized patterns of behaviour. The study of institutions offers a means of examining the basis of routinized action from the viewpoint of the system as a whole (Hodgson 1988, 10).

The evolutionary approach in economics means, on a highly general level, that certain ideas, concepts and modes of thought are **imported from biological, thermo-dynamic, or respective natural sciences into economics**. They provide analogies and suggest problems (without supplying ready answers to problems) and thereby are expected to improve the analysis (Saviotti and Metcalfe 1991, 19; Nelson 1987, 12). Metcalfe, for example, stresses that biology is not the only evolutionary science but rather one of many applications of the particular mode of evolutionary thinking (Metcalfe 1993, 5).

The economic articles by Lundvall, Verspagen, Kuusi, Pantzar, and Loikkanen in this volume are closely related to recent tradition in the evolutionary economics of technological change[3]. In this tradition the mode of thought and interpretations may differ from other traditions in evolutionary and institutional economics. Some of the contributions in the evolutionary economics of technological change are *inter alia* Nelson and Winter 1982, Freeman (1992), numerous papers of Nelson (e.g. 1987), Dosi et al. (eds 1988), and Saviotti and Metcalfe (eds 1991).

Evolving Technologies: The Kuhnian Approach

The traditional "production function" viewpoint has supposed that technological change is a global phenomenon without a specific direction. The new "Kuhnian viewpoint" of technological change refutes these assumptions (Verspagen 1992, Dosi 1982). Dosi draws an analogy with Kuhnian philosophy of science (Kuhn 1970) and assumes that "normal" technological change consists of relatively small improvements to bigger, revolutionary (and therefore "scarce") **technological breakthroughs**. The discoveries are supposed to be grouped in **technological paradigms** based on

[3] According to Dosi, evolutionary theories are a rather heterogeneous set of modeling efforts which share the emphasis of the dynamic properties of economies characterized by the repeated emergence of various forms of innovation, decentralized processes of discovery and the historical persistence of particular patterns of change (Dosi 1991, 354).

different technological breakthroughs. Other analogous concepts are "technological regimes" (Nelson and Winter 1977), "technological guideposts" (Sahal 1981, Rip 1995) and "megatechnologies" (Kuusi 1991). Dosi defines a technological paradigm as a "model and pattern of solution of selected technological problems, based on selected principles from natural sciences and on selected material technologies" (Dosi 1982).

The definition of a technological paradigm links up with Schumpeter`s innovation theory, in which an important innovation creates a bandwagon effect of smaller, **incremental, follow-up innovations**. Dosi (1982) uses a similar concept when he makes the distinction between technological paradigms and technological trejectories. In his view, "normal" technological change (compare the Kuhnian term "normal" science) takes place along a direction set out by the discovery of an important general principle which provides the opportunity for application in a number of economic sectors. A **technological trajectory** is the development of a technology along the lines set out by the technological paradigm.

An important dimension of a technological paradigm is its pervasiveness. Perez (1983) has introduced the term techno-economic paradigm to make a distinction between pervasive and non-pervasive technological paradigms. A **techno-economic paradigm** describes the economic, institutional and technological inter-linkages between sectors. A new technological paradigm will thus also imply a shift towards a new techno-economic paradigm if the technological principle (or the products associated with it) can be used throughout the economy, so that institutional and economic relations between all economic agents are affected.

Verspagen (1992) takes as examples of techno-economic paradigms steam power, electricity and iron and steel fall. Evident current examples are revolutions in microelectronics and biotechnology. The takeoff of a techno-economic paradigm will require new investments and thus implies the creative destruction of old capital in most sectors. The macroeconomic effects of less pervasive technological paradigms are much smaller. The main effect is limited to one or a few sector(s) of the economy.

To a certain extent, technological paradigms will always be exogenous to the economy. What is economically possible is bounded by what is technologically possible. And what is technologically possible will always be limited by scientific principles (or laws) like gravity, the speed of light, etc.(Verspagen 1992). Scientific discoveries do not, however, determine the successes of technological paradigms, as has been often supposed in the traditional production function approach with the exogenous technological development.

What determines the competitiveness of a paradigm? Freeman (1991) makes a distinction between technological, economic and institutional factors in competitiveness.

Technological competitiveness relates both to production costs (process innovation) and quality (product innovation). According to Freeman, technological competitiveness is increased by incremental innovations, which to a large extent take the form of learning effects. Due to their cumulative nature, the impact of incremental innovation and learning effects differ over the lifetime of a technology. Freeman assumes that in the initial (laboratory) phase of the development of a technology, progress may be very slow. But after a certain period of introduction, it is likely that incremental innovations and learning effects take place at increasing rates. In the later phases of the development of the paradigm, so is often remarked, decreasing marginal returns to research efforts set in and learning effects become smaller and smaller.

In a learning process **network externalities** are important. If there are enough exploiters of a technological paradigm communicating with each other and forming a part of a larger communication network in a market or elsewhere, it increases both incremental innovations and the number of users in the network. Due to specific historical circumstances, such as the existence of a competing technology or the specific institutional setting, a new paradigm may not reach this "critical mass" of users in some well-established production networks. This gives a chance to less well-established production networks e.g. for new or small firms.

The economic and institutional factors which detemine the competitiveness of a technological paradigm are connected with the **developer community** of the paradigm. With the concept of the developer community we refer to a wide network of developers, applicators or regulators of a technological paradigm (Kuusi 1991). Analogous concepts are the **"technological community"** (Nelson 1993) or the **"development block"** proposed originally by Erik Dahmén (Edquist - Lundvall 1993). A developer community includes not only producers, who use the new technology, but also the buyers and users of their products; the developers and educators of scientific bases of the technology; and representatives of e.g. public authorities, organizations of consumers and labour unions, who promote the use of the technological paradigm. It is important to notice that also active critics of the paradigm belong to its developer community. A developer community has an active or influential **core** and a passive or powerless **periphery**.

Evolving Technologies: The Evolutionary Approach

The evolutionary approach and the Kuhnian approach to technological change are complementary to each other. The evolutionary approach especially gives tools for microeconomic explanations of technological change (Verspagen 1992). Instead of the neoclassical microeconomic explanation of technological change as the increase in productivity of all techniques available, technological change on the firm level is based on an **active search** for new techniques. "Diffusion laws" of new techniques are supposed (Verspagen in this volume), which are analogous to the diffusion laws of living organisms.

We may draw a parallel between an **invention** and a gene. Nelson and Winter (1982) drew another parallel. In their model routines in firms act as relatively durable genes. In biology a gene is the part of DNA which codifies the production of a single protein (e.g. Kuusi 1991). The "idea" of a gene is to be the smallest discernable functional unit of DNA. Routines, however, are combinations of many discernable social and technical inventions. It is reasonable to interpret a routine as a combination of many genes.

A **generic invention** means that the same "gene" can function in many different types of products or production processes. If a product or production process, where an invention X is applied, is successful in a market, we may call, in analogy with Freeman (1982), the new product or production process an **innovation** based on invention X. In analogy with a generic invention, we may speak about a **generic innovation** or a **generic technology.** A generic technology functions well in many different types of products or production processes.

As a gene with other genes, so an invention can function well only together with some other inventions. A carburetor, for example, is an application of generic technology of vaporizing a liquid and mixing it with a gas. The same technology applied in the painting industry might become an automatic paint sprayer or in the aerospace industry a jet backpack.

A paradigmatic technological breakthrough in the Kuhnian approach and a generic technology in the evolutionary approach have similar roles. A generic innovation can successfully function with different types of technical solutions or "combinations of genes". On the other hand an incremental technical innovation may function only in combination with a specific generic innovation.

Selection and **variations** are important concepts of the evolutionary approach. In his article in this book, Pantzar has described their roles in the evolutionary perspective:

> By socio-economic evolution I refer to the interaction of processes which generate variations (e.g. inventions and innovations), transmit variations through time and space (e.g. learning and imitation) and restrict variations (e.g. selection as a result of competition and cooperation).

The idea behind Pantzar´s definition is that the market economy is not a simple problem solving machine. It is what cybernetiticists have called a **self-organizing system**, a system that can and does modify its own structure and programming in the course of, and as a result of its own operations. Pantzar refers to Herbert Spencer´s definition of evolution, which is in his mind still illuminating: "Evolution is definably a change from an incoherent homogenity to a coherent heterogeneity, accompanying the dissipation of motion and integration of matter" (Spencer 1862).

An important aspect of a Self-Organizing System is **replication** (Pantzar 1991 p.150-151, Csanyi 1990). Temporal replication is the continuous renewal of the system in time, ie. self-production. Spatial replication is identical to that of reproduction. The system produces its own copy, which becomes separated from it in space. From one system or unit, two or more units are formed. The possibility of a system´s simultaneous functional differentiation and integration depends on the certainty that all sub-systems replicate and coordinate properly. In other words: the evolution of systems of interdependence demands high fidelity of component replication.

It is an interesting hypothesis that different technological paradigms or generic technologies demand and produce different replicative systems. The replication concerns not only physical objects but also ideas, e.g. production routines of organizations.

What is the relationship between the "steam power paradigm" and the development of a replicative system of railroads in the USA in the nineteenth century? The loosely interconnected railroad system of the 1860s contained many different kinds of separate subsystems, which were all replicative units (Chandler 1977, Pantzar 1991). When these subsystems expanded, interrelationships among them developed and total replication become coordinated.

The replication conditions of technological paradigms differ. As in living nature, major changes in an environment may make some earlier insignificant inventions (genes) crucial for survival. E.g. we may draw a parallel between the success of some old environmentally sound inventions, which have become important, and those genes which saved mammals at the time of the fall of the dinosaurs.

Evolution, learning and replication are closely interconnected. Evolution is based on replication, as shown above. If there is no genuine learning, it is reasonable to assume that nothing really new (no evolution) happens, if the environmental conditions remain stable. On the other hand, we say that somebody has learned to do something, e.g. make a table, if he can replicate (or realize) the idea of the table.

"Darwinism" vs "Lamarcism" in Economics

In the evolutionary economics of technological change the cumulative nature of knowledge is a central factor in introducing novelties to the system. According to Boulding the production has originated in a genetic process of know-how, increased by human learning, which is able to use energy to select, transport, and transform materials into products (Boulding 1991, 12).

Nelson interestingly argues that the most sharply distinguishing features between biological and technological evolution may relate just to the public and private aspects of technology (Nelson 1990, 6). New findings, understandings and ways of doing things do not adhere only to their creator and their descendants, but are at least to some extent public and shared among contemporaries. The sharing may be intentional or unintentional and may occur also despite the efforts to keep the findings privy[4].

Many evolutionary economists have proposed that the evolutionary theory of technical change may be called "Lamarcian" because the acquired characteristics are "inherited" and purposely passed on through learning (Metcalfe and Saviotti 1991; McKelvey

[4] As Nelson reminds us, already Schumpeter stressed that, in the general run of things, the monopoly is temporary and the benefits of successful innovation are spread widely (Nelson 1990, 6).

1991; Freeman 1992, 198, Verspagen 1992). Nevertheless, we think that the division of economic evolution approaches into "Darwinism" and "Lamarcism" is too simplistic. It is important to realize that there is a variety and not only two types of learning systems with the following properties:
- the system is able to change its behaviour in response to experiences
- the system has targets or interests, which guide its choices
- the system has a memory to store experiences relevant to the being's behaviour.

Even Darwinian evolution is more complicated than is commonly realized. The basic "interest" in the evolutionary learning of nature is survival or repliction (e.g. Pantzar 1991). The relevant experiences are stored beside the neural networks in the DNA- or RNA-memories of organisms. DNA or RNA molecules are **active** memories of every living cell. These memories do not change only when two genetically different organisms get a common descendant. In single cells DNA-memories can change essentially e.g. when viruses connect themselves to DNA-molecules or when radiation changes the order of bases or nucleotides, resulting sometimes in the uncontrolled fission of cells (the formation of cancer cells).

Organizations are different learning beings. Organizations encode inferences from history into routines. Routines are recoded in a collective memory that is often coherent but is sometimes jumbled, that often endures but is sometimes lost (Levitt and March 1988). The collective memory has many concrete places e.g. the brains of the persons in the organization or persons communicating with it, written documents or computer files.

Controversal Concept of *Holism*

The importance of the *holistic* approach is often stressed in the context of institutional and evolutionary research tradition, as well as in that of future studies[5]. In the tradition of future studies the content of *holism* is, however, broader and, respectively, also looser. We discuss shortly the issues relating to this controversial concept. By *controversial* we refer to the imprecise nature of holism when considered or used in the context of economics.

Wilber and Harrison have summarized the main characteristics of the institutional economic approach as follows: "At the most general level, institutional economics may be characterized as *holistic, systemic and evolutionary* (Wilber and Harrison 1978, 71)[6]. Social reality is seen as more than a specified set of relations; it is the process of change inherent in a set of social institutions which we call an economic

[5] *Holism* was originally coined by the South African scholar Jan Christiaan Smuts from the Greek word *holos* which means whole. He applied the term in categorizing the new type of theories (Darwin´s, Becquerel´s, Einstein´s) in the physical sciences that were gaining widespread recognition in his time. These new evolutionary or dynamic theories had displaced the old inherited mechanistic scientific theories of Newton and the pre-Darwinian world (see e.g. Wilber and Harrison, 1978, 73).

[6] These characteristics - holistic, systemic, evolutionary - combined with the appreciation for the centrality of power and conflict and the recognition of the importance of non-rational human behaviour - differentiate institutional economics from standard economics (Wilber and Harrison, 1978, 71).

system. The process of social change is not purely mechanical; it is the product of human action, but which is definitely shaped and limited by the society in which it has its roots. Thus institutionalism is holistic because it focuses on the pattern of relations among parts and the whole. It is systemic because it believes that those parts make up a coherent whole and can be understood only in terms of the whole. It is evolutionary because changes in the pattern of relations are seen as the very essence of social reality."

Wilber´s and Harrison´s characterization of institutional economics is accepted and reiterated by several evolutionary and institutional scholars. Freeman, for example, emphasizes that the approach of the authors of the volume *Dosi et al* (1988) is based on the principles expressed above by Wilber and Harrison (Freeman 1988, 4). Interpretation of Wilber and Harrison is accepted also by Clark and Juma as a starting point into their book (Clark and Juma 1987, 16). *Holism*, including pattern models and storytelling, expresses the belief that a change in subject matter requires a change in method (Wilber and Harrison 1978, 62). Hodgson specifies his interpretation of holistic as follows: It embraces questions of the determination and evolution of tastes and preferences (Hodgson 1988, 17).

In summary, in the context of institutional and evolutionary economics the concept of holism emphasizes the dynamic relations of the parts and the whole of social reality, bounded behaviour of actors, as well as respective required methodologies, such as a systems approach. In the tradition of future studies holism is, however, often understood more comprehensively than within evolutionary and institutional economics.

We can take as an example a recent paper of the well-known future-researcher, Ervin Laszlo, who gives an interesting formulation of the holistic approach. Laszlo develops a concept of an "holistic cognitive map", meaning a way of thinking about man and nature and the relationships between them (Laszlo 1993, 61-63). He starts by analysing man´s wide-ranging master over nature and concludes that a shift is occurring today to holistic cognitive map which highlights co-operation and co-evolution. The transfer from the previous cognitive map to the emerging holistic map is characterized by such transformations as from anthropocentric to humanity; from Eurocentric to diversity of cultures; from atomistic and fragmented to cooperation and co-evolution between people (and people and nature); from materialistic to innate purpose; from material, goods, technology, compete-to-win to education, communication, control of people; from material growth as social progress to sustainability, balance and adaptation of the biosphere; from economy as a struggle for profit and survival to cooperation and valuation of diversity; from separable sickness and impersonal treatment to inseparable body and mind; from an outsider-God to non-diverse spheres of reality; from hierarchical and concentrated power and wealth to participatory and global orientation.

The scope of Laszlo´s hypotheses is extremely ample and the issues, although proclamation-like, are, no doubt, relevant in many ways in characterizing and outlining the mega-trends of global social and ecological developments. On the other hand, such a comprehensive meso-approach as Laszlo´s is also problematic, especially when compared to the precise variables and approaches used conventionally in economics - whether standard, institutional or evolutionary ones. Laszlo´s foci are in the relationship between man and nature, a global view, multidisciplinarity and an enormous number of variables. Consequently, a certain imprecision in the analysis is unavoidable. Although more systemic approaches, supported by advanced computing and other measurement technologies, may improve the mastery of even extremely large numbers of variables, it is clear that on the operational level of exploration the problems mentioned by Laszlo may be treated only on a highly aggregated level, as is done, for example, in the work of Club or Rome (see e.g. Meadows, Meadows and Randers 1992). Nevertheless, regardless of the importance of those efforts, we think that such a comprehensive analysis may remain peculiar or distant to the economists working either in the context of the standard approach or within the institutional and evolutionary framework.

Applications of Evolutionary Theories in Policy Studies and Technology Foresight

The concept of a **national system of innovation (NSI)** has been accepted fairly rapidly into the terminology of policy-makers in the industrialized countries (see e.g. Towards..., 1993). McKelvey defines NSI as processes of innovation and diffusion in the context of the production system and of social and economic institutions (McKelvey 1991, 118). Nelson and Rosenberg define NSI as a set of institutional actors that, together, plays the major role in influencing innovative performance (Nelson Ed. 1993, 4-5). According to Lundvall (this volume) the concept of NSI can be regarded as a tool for analysing economic development and economic growth.

Some of the contributors of the NSI concept are Freeman, Lundvall and Nelson. McKelvey considers in her comparative analysis of different SNI approaches also Porter´s analysis within the NSI context. Perhaps the *national* in the concept of NSI is the most debated today - in period of strong techno-economic globalization. Lundvall gives answers to this controversial issue in this volume.

The analysis of NSIs is closely related to the accentuations of evolutionary and institutional economics. For example, Lundvall stresses in his paper the importance of the systemic approach, the role of the institutional set-up as well as interactive learning. In his opinion the recent developments of evolutionary economics offer a well-suited theoretical framework for a more systematic theoretical underpinning of the national system of innovation.

The concept of NSI is particularly related to the concepts of development blocks, clusters and developer communities of technologies. Although the national developer communities of technological paradigms or generic technologies (e.g. the national developer communitities of new biotechnology) have many links (e.g. through research programmes of the European Union), the national institutional and regulatory frameworks are still highly important.

Evolutionary theories have been a theorethical framework for many **technology foresight** studies. The idea of rational technology foresight is to reason innovations and production decisions from already made inventions, and possible new innovations from realized and potential market demands. Technology foresight seeks answers e.g. to the following questions: Can a product based on a new technology win markets shares? What are promising new application areas in the long run for a new technology? How can technical development face the market demand? Where to allocate R&D resources in companies and how to formulate a technology policy? In practice technology foresight studies do not answer only specified questions. An important function of technology foresight studies is to make new conceptualizations or to find new important questions. This important function is discussed in the article of Annele Eerola in this book.

Both the Kuhnian and evolutionary approaches to evolving technologies give tools for technology foresight. Different technological paradigms and their technological trajectories are based on different models of solution of technological problems. They implicate different scenarios of technological development. Jorma Lievonen gives in this book an example of the paradigm change in 1980s in telecommunication technology, which give opportunities to newcomers like the Finnish Nokia Corporation. The study of generic technologies gives insights into the general conditions of the diffusion, as is more closely exmined in the article of Osmo Kuusi.

Technology foresight studies have had different purposes. Different organizations (e.g.firms and educational organizations) need technology foresight for their decision making. An important application area, which has motivated large technology foresight studies, has been standardization. Jorma Lievonen compares in this book the standardization efforts in telecommunications with technology foresight studies.

The Kuhnian and evolutionary explanations of technological change are critical to the trend predictions of technological change. Another much used information source of future technologies has been expert knowledge. We see that, in order to attain a comprehensive understanding of the future directions in technological development, both expert knowledge and the use of trend techniques, completing each other, are needed. Certifying the expertise of experts and defining the impact of their interests, e.g. in the delivery of information, are the two basic problems in expert knowledge.

Qualified experts in future technologies are often the same persons who have the strongest economic or other interests concerning decisions affecting future technologies. The quality and features of expert information differ essentially depending on the purpose and the audience of technology foresight studies. Annele Eerola gives in her article a useful typology of technology foresight studies, which helps to cope with these problems. Osmo Kuusi discusses the relationship of interests and exposed expertise of different expert groups of future technologies, e.g scientists in basic research and experts in business, in public organizations or in consumer organizations.

Emerging technological paradigms or generic technologies diffuse through innovation processes based on them. A closer examination of the phases of innovation processes may identify the obstacles of diffusion and the role of incremental innovations and market demand. This topic is discussed in the article of Kuusi. In the **science push** model the starting point of an innovation process is a technical invention. In the **demand pull** model the starting point of the process is market demand.

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REFLECTIONS ON HOW TO ANALYSE NATIONAL SYSTEMS OF INNOVATION

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Why Study National Systems of Innovation?

The most fundamental reason for studying national systems of innovation is that the perspective helps us understand new phenomena and to adapt economic theories, policies and institutions to what is going on in the real world. Today the analysis of national systems has a critical dimension: it evokes a need for change in economic theory as well as in institutions and policy.

Neoclassical and new classical economics focus on problems of allocation in a general equilibrium context. The perspective is one were individual agents with given preferences, amounts of information, including a given stock of publicly shared technical knowledge, make rational decisions. On the basis of the analysis, normative conclusions about how the economic system should be organised are drawn. This theoretical perspective, where scarcity is at the core of the analysis and where there is little room for genuine uncertainty, might be useful for the analysis of partial and short term issues such as for instance the first order reactions to shocks (as illustrated by the dramatic rise in the price of crude oil in the seventies and the eighties). It is less adequate though for the analysis of economic development.

When the objective of the analysis is better to understand and to analyse economic development the process of innovation - the on-going creation and diffusion of new things and new ways of doing things - must be taken into account. Innovation may be embodied in tangible goods (product and process innovations) or disembodied (new marketing techniques as well as institutional and organisational innovations). Today, the rate of change in all these dimensions is rapid and the firm or the country which were to use all its efforts to allocate existing resources in a better way but where every single unit kept producing the same product with the same techniques would not only stagnate; it would gradually become increasingly poor because its products would become less and less in demand. Therefore, when the focus is on economic development, successful innovation is more important than efficient allocation.[1]

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[1] This is a major point made in the extremely important introduction to Pasinetti (1981) where he argues that the focus on scarcity were more adequate for pre-industrial economies where wealth was (more) rooted in trade in natural resources than in learning and innovation.

In this perspective, it becomes clear that the information and knowledge which agents have may be less important than their learning capability. Again, in a rapidly changing world, the very well-informed and knowledgeable agent - be it an individual or a collective unit - would soon find him/her/themselves by-passed by competitors if he/she/they did not learn anew and this includes learning to do new things and to handle new situations as well as getting access to new information.

One basic intention behind the concept of national systems of innovation is thus to change the analytical perspective away from allocation to innovation and from decision-making to learning. This can be illustrated in the following way.

Table 1. The NSI-perspective contrasted with the standard neo-classical perspective

	Allocation	Innovation
Decision-making	1. Standard Neoclassical	2. Neocl. on innovation
Learning	3. Austrians	4. NSI-perspective

It is interesting to note that the learning perspective can be applied also to allocation. This is the case in certain Austrian contributions where the entrepreneur in connection with the market process is obtaining profit through exploiting the void of ignorance separating suppliers from users (Kirzner and Hayek). It is also interesting to note that certain aspects of the process of innovation have been approached from a neo-classical perspective of rational choice (selection of R&D-projects, allocation of R&D-resources as a process of rational choice). It is only when we combine innovation and learning in the analytical perspective that we effectively transcend the limits of the neo-classical paradigm.

Until quite recently the analysis of innovation was, with the major exception of Schumpeter's contributions, a rather minor and therefore also a little controversial speciality in economics on line with other fields of applied economics such as agricultural economics or labour market economics. It is only lately that the potentially revolutionary character of the approach has become recognised. It reflects among other things the character of learning and innovation. For instance it is not reasonable to analyse a process of learning and innovation without bringing fundamental uncertainty into the picture. To do so would boil down to the contradictory assumption that learners already knew everything which could be learnt in advance and that innovators knew all possible outcomes of the process of innovation. I would argue that there is no other perspective on the economy which to the same degree challenges the neoclassical orthodoxy.

The NSI-approach is critical to derived dogmas about the *general* superiority of pure markets and of maximum flexibility in the conditions of the wage-earners.[2] This

[2] It should be noted that flexibility is not sought in all institutions by neo-liberal economists. Private property rights should be clearly defined and made as rigid as possible. A focus on learning and innovation demonstrates the need for a mixture of rigidity and flexibility in most economic relationships. Interactive

reflects the assumption that innovation is rooted in processes of *interactive* learning and interactive learning does not thrive in pure markets. Especially in labour markets, industrial relations and inter-firm relationships, elements of 'rigidity' - of long-term non market relationships involving authority, loyalty and trust - are *necessary* to make learning possible. The pure market economy populated by short termist, individualist rational men characterised by adaptive behaviour would if it could be reproduced in reality get close to what Schumpeter has defined as a state of *Circular Flow*. Little learning would take place, few innovations would be introduced and the economy would be stagnant. It would definitely be another world than modern capitalism.

On the Importance of Institutions

The focus on *interactive learning* evokes also the important role of economic structure and institutions in determining the rate and direction of innovative activities. *Institutions* understood as norms, habits and rules are deeply ingrained in society and they play a major role in determining how people relate to each other and how they learn and use their knowledge (Johnson, 1992). In an economy characterised by on-going innovation and fundamental uncertainty the institutional setting will determine how the economic agents behave.

Which are the most important institutions in this context? I would like to sort out four examples of informal institutions: the *time horizon* of agents, the role of *trust*, the *actual mix of rationality* and the way *authority* is expressed.

The now almost generally accepted distinction between short termism as characterising corporate governance in Anglo-Saxon countries and long termism in for instance Japanese investment decisions is one important example of how institutional differences have a decisive influence on the conduct and performance at the national level. It is quite obvious that this distinction is important not only for the allocation of finance but also for other aspects of technical innovation. Certain technology areas will only be possible to develop into commercial success by agents who operate from a long term perspective while others might be easier to exploit with a short term horizon.

The second example relates to the role of trust in the economy. Trust is a multidimensional and complex concept which refers different kinds of mixes between expectations about consistency in behaviour, full revelation of what agents regard as relevant information for the other party and in general good intentions. The institutions which constitute trust are crucial for interactive learning and innovation capabilities. The strength and the kind of trust embedding markets will affect transaction costs and it will determine to what degree interactive learning can take place in connection with the market relationship. Formal and legal arrangements around the market will reflect this tacit social dimension.

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learning does not thrive in pure markets and very rigid definitions of property rights in relation to knowledge and information would - in cases where they could be imposed - be a certain way to undermine the innovative capacity of the economy.

A third category, and this is perhaps the most fundamental when confronted with standard economics is the pre-dominating rationality. It is normally assumed either that instrumental and strategic rationality is a general rule for human behaviour or at least that it dominates completely in the private economic sphere. Economic transactions in the form of single and isolated exchange acts in a capitalist environment tend to support patterns of behavior corresponding to instrumental rationality. When we take into account the importance of learning, including learning new skills through interaction with other agents, it is no longer the only kind of behaviour which will be selected. If the instrumental rationality were completely dominating the behaviour of professors and students, masters and apprenticeships as well as engineers from R&D-labs belonging to different firms, very little learning would take place. Innovation systems where communicative rationality were playing a major role in the private sector would therefore be better off in the long run than the standard exchange economy (Habermas, 1984).

Finally, it is difficult to disregard the importance of different forms of authority in connection with industrial relations and also in the relationship between organisations of different economic strength. As pointed out by Polanyi (1958) the learning of new skills, which are important for the evolution of the innovation system, will typically take place in the context of a master-apprenticeship relationship where a mixture of trust and authority is necessary if learning should be efficient. One reason that the Asian economies seem to have an outstanding capability to learn might be rooted in the kind of authority relationships which have established themselves historically.

An important next step in this area is to develop indicators which reflect these and other critical institutional dimensions and introduce them in an analysis of the conduct and performance of innovation systems.

The Role of Structure and Specialisation

If institutions define *how things are done* and how learning takes place it is the economic structure which affects *what is done* and therefore what is learnt. It should not be too controversial to argue that *the economic structure* differs between countries. For instance, international specialisation is at the very core of neo-classical trade theory. What is important is that the specialisation reflects advantages which have been created by cumulative processes of learning rather than 'natural' comparative advantages.

Recent empirical research by Archebugi and Pianta and others using a combination of trade specialisation data and patenting data demonstrate that there is in fact a very strong correlation between the specialisation in trade and production on the one hand and the specialisation in the knowledge-base on the other. The economic structure and the pattern of specialisation will reflect accumulated learning and at the same time it will be a major factor in determining the direction of future learning and innovation. This reflects the fundamental assumption behind the system of innovation approach: that interactive learning is rooted in routine activities and that most search activities will be closely oriented toward problems emanating from the existing set of economic activities.

Do Institutions Shape Structure or is it the Structure Which Determines the Institutional Set-up?

Among those who recognise that national differences exist some have argued that the differences emanate mainly from structural characteristics (Malherba, 1995). In principle the composition of the economy in terms of sectors or technologies may explain completely the institutional differences between countries. If this were the case a kind of revised neo-classical history might be constructed. First, countries became specialised in specific products - reflecting for instance the relative scarcity of factors of production and raw materials. Given the resulting specialisation the institutional characteristics were established.

Others have taken the opposite road and try to demonstrate that the institutional set-up is a major factor in determining the specialisation of the national economy (Guerreri and Tylecote, 1995). They try to predict the pattern of technological and sectoral specialisation of the national economy by characterising it in terms of its institutional characteristics.

Both these perspectives may be partially right. On the one hand it is reasonable to assume that the historical pattern of specialisation which often had its roots in access to natural resources has affected the institutional set up. Once this institutional set-up has become established it is reasonable to assume that it will attract those industries which are most compatible with it. The two perspectives converge in their emphasis of the fact that the two dimensions of the innovation system are interdependent. This interdependence is one reason why it is meaningful to apply a system's perspective.

But some care should be exercised to avoid simplistic functionalist reasoning. As a matter of fact the main reason for differences in performance between national systems may be that the degree of matching between structure and institutions differences among countries (Freeman, 1995). Institutions may be rooted far back in social history and they might be slow to adapt to the change in economic structure. Therefore one should not expect a one to one correlation and the kind of analysis referred to above could have as its most important outcome a better understanding of why a complete matching does not appear and how this affects the performance of systems of innovation.

Why National Systems?

Quite a number of people have welcomed the concept of the system of innovation but have been critical to the focus on national systems[3]. There has been numerous

[3] It is thus interesting to note that in the Cambridge Journal of Economics' special issue on national systems of innovation there are few articles besides Christopher Freeman's which focus on national systems.

contributions trying to refocus the analysis on other levels of analysis such as the region, the firm, the technology and the sector. At least in some cases these studies present themselves as more relevant alternatives to an analysis of national systems. Some are critical because they argue that the national level is not the most relevant when it comes to analyse innovation; innovation systems are rather local or transnational than national in scope. Others have been critical for political reasons. They have argued that the very fact that the focus is on the national level invites policy-makers to look for protectionist solutions or beggar-thy-neighbor policies. Krugman is making a similar point in relation to the concept of competitiveness when applied to a nation.

Recently a number of empirical studies have analysed the issue by the use of trade and patent data (see for instance the articles by Archibugi & Michie, Patel, Fagerberg and Cantwell in no 19, 1995 of Cambridge Journal of Economics). The debate is far from closed but the following conclusions seem to be reasonably well established.

1. There is no doubt regarding the fact that national innovation systems as well as systems of production are specialised and there are no signs of convergence in this respect.

2. Transnational firms tend to locate more of their development efforts abroad but the tendency is not very strong and most of these activities remain domestic rather than transnational.

3. The diffusion of innovations and the use of new technology becomes increasingly transnational. In order to receive foreign technology and to integrate it the absorptive capacity of the national system plays a key role.

4. Home markets in the form of advanced domestic professional users seem still to play an important role in promoting innovation.

To demonstrate the institutional differences between national systems is more complex and less easy to do by international statistics. To illustrate the point we (Edquist & Lundvall, 1993) compared two economies - Denmark and Sweden - which are as close as possible in terms of culture, history, geography etc. and showed that even for these countries the differences in terms of institutions are quite remarkable. The Made in America-, Made in France-studies (Dertoutzos et al and Coriat) and others lead to the same kind of conclusions.

But even if the tendency toward globalisation of innovation activities were much stronger I would still argue that the analysis of national systems is important for the following reasons:

- Standard economics is extremely national in its analytical focus. This is true for almost all applied research in the field including the analyses by international organisations such as OECD, the World Bank etc. Analytical work on aggregates for multinational regions or at the level of the global economy is still marginal and exceptional. As a result the national dimension is already there but it remains unreflected and unspecified - almost in a sub-conscious form. Explicitly emphasising national systems may actually contribute to make the national dimension of standard economics explicit and a possible target for criticism.

- The dominating discourse regarding economic policy - including monetary and fiscal policy as well as labour market and social policy - refers to the national level. To abstain from analysing innovation at this level implies that the economic policy discourse becomes completely dominated by a static allocation perspective. Actually this kind of imbalance in the debate is one major reason for the hegemony of a simplistic neo-liberal policy agenda.

- Some experts have challenged the national perspective with a reference to the process of globalisation and the process of regional integration and especially the formation of the European Union. There is little doubt that we are in the midst of a process of change which affect the economic role of the nation and specifically the location of innovation activities in this context. But rather than concluding that the national level becomes analytically less relevant I would argue that this is yet another reason for analysing the role of national systems of innovation. In passing, Pasinetti (1981) discusses the historical role of the nation state as a framework for economic growth and for the promotion of learning among producers and users. The modern welfare states developed in the post-war period may be regarded in this light. They did not only - and this is the aspect rightly emphasised by the Regulation School - ascertain an income distribution which was compatible with a kind of macro-economic equilibrium. They also made it attractive and less risky for broad segments of the population to participate actively and positively in the process of learning, innovation and change.

It is correct that Globalisation and the European integration represent strong and complex challenges to the historically constructed welfare states and to the existing national systems of innovation. It is difficult to see how these challenges can be understood if we do not take our starting point at the national level. And without such an analysis it is also difficult to understand what kind of international institutions are needed as substitutes for the old national systems when these are undermined. The stronger the threat to undermine the national systems the stronger the need to understand their historical role.

Two Approaches to National Systems of Innovation

Some authors, especially from the US S&T-tradition, tend to regard the NSI-concept simply as an incremental follow-up and broadening of earlier analyses of national science systems and national technology policies (see for instance the definition given in Mowery, 1995, p.80). To them bringing together indicators of national specialisation and performance regarding innovation, R&D-efforts and S&T-organisational framework is both the instrument and the aim of the analysis. The policy issues raised are typically related mainly to science and technology policy. They are reluctant to recognise the national dimension since they see it as evoking a threat in them shape of techno-nationalism.

The approach developed by Cristopher Freeman (1985) and the 'Aalborg-version' of the national innovation system-approach (see Lundvall, ed., 1992) go further, however. Especially, it takes as its starting point the fact that important parts of the knowledge-base emanate from routine-based learning-by-doing, -using and -interacting and not only from search activities related to science and technology. This is why we have argued that the prevailing economic structure and the institutional set-up (understood as socially shared routines, norms and modes of problem-solving) is at the centre of the NSI-analysis. The policy implications are also more far reaching. Typically they will include not only science/technology and industrial policy but also policies relating to human resource development and to the institutional set up of markets for labour and finance. Even the ethical foundations of society is important from this perspective - including how it treats the losers in the process of change - and it evokes considerations about income distribution and social policies.

In this sense the Freeman/Aalborg approach is more ambitious and more apt to seek a broad confrontation with new classical economics both at the theoretical and the political field.

Is There a Theory of National Systems of Innovation?

The concept National Systems of Innovation can be regarded as a tool for analysing economic development and economic growth. It has in common with growth accounting that it tries to bring together the major factors which affect technological progress as registered in standard neo-classical growth models. It differs in being more explicit in terms of the institutional assumptions made and especially in avoiding any assumption about factors being independent. This reflects the system's perspective and the emphasis on virtuous and vicious circles or match and mismatch between elements and subsystems.

The concept is historical in the sense that the innovation process as well as the role of national borders change over time. This does not exclude that there is a strong need for a more systematic theoretical underpinning of the concept, however, and recent developments in evolutionary economics offer a theoretical framework which is well-suited to fill this function. The emphasis on qualitative change and on the creation of diversity makes it possible to integrate important aspects of the process of learning and innovation, National systems may be regarded as offering distinct regimes of diversity creation, selection and retention where the institutional set up plays a key role and the outcome is an evolving knowledge base or an evolving economic structure.

What should always been remembered when applying such evolutionary schemes is that the similarity with biological processes may be devious and lead us to a biased perspective. Most importantly, the regimes of retention (reproduction), diversity creation and selection are not in any way given by nature and as a matter of fact it might be argued that the most interesting on-going political discourse will always be on how to design or regulate these regimes (cf. the debates on plan versus market, anti-trust legislation and the role of social policy etc.). The use of models of selection should not obscure the fact that the rules of the game are constantly a debatable issue. There is always some risk for determinism in the evolutionary perspective either because outcomes seem so complicated and uncertain that intervention seems vain or because firms and people are treated as objects rather than subjects.

The Policy Perspective

National systems of innovation is a concept which has been integrated very rapidly in policy analysis at the national as well as the international level. It is as if there was some potential unsatisfied demand for the concept even before it was introduced on the research agenda. So far the main use has been in connection with analysing extended science and technology systems in order to improve their performance.

The policy potential might be much wider however. In order to avoid irrationally based international economic conflicts a minimum of mutual understanding of the national systems is important. The present conflict between the US and Japan could possibly be given a less damaging impact on the world economy if the systems were better understood by the parties involved. In a global economy dominated by Trilateral relationships this is becoming quite important.

The other side of the coin is the potential for international institutional learning. Much of the management literature is about transferring elements of systems of innovation across borders. A system's perspective is useful in order to avoid naive imitation and copying and promote institutional learning.

The even more ambitious goal would be to get a complete review of all main economic policies in the light of their impact on innovation and learning. It is far from evident that policies and institutional reforms aiming at promoting efficient allocation also promote innovation. This would have an impact on the design of labour markets policies and industrial policies as well as on the design of financial systems and systems for education and training.

Finally the perspective of national systems of innovation may offer a basis for the development of a new and more coherent set of strategies for developing countries and for the countries in Eastern Europe. The World Bank emphasis on stability is insufficient when it comes to promote development. Also if it is not obvious at first sight it is true that even the most primitive economy must engage in learning and competence-building if it wants to strengthen its relative position in the world economy. Some countries may start development from their raw material basis but if they do not build competencies and absorb new technology they will be stuck in poverty.

EVOLUTIONARY THEORIZING ON ECONOMIC GROWTH

Gerald Silverberg* and Bart Verspagen**

Introduction

While an evolutionary perspective has been urged upon economists since at least Marshall 1890 (see Hodgson 1993 for a recent reiteration), what has been lacking until recently, at least for a large portion of the economics profession, has been a body of formal theory and quantitative analysis on an explicitly evolutionary basis. This has changed since the work of Nelson and Winter in the 1960s and 1970s (summarized in Nelson and Winter 1982), which operationalized and extended many of the concepts going back to Schumpeter 1919, Schumpeter 1947, Alchian 1951, Downie 1955, Steindl 1952, and others. Since then a number of authors have been enlarging on this foundation and systematically extending the evolutionary economics paradigm in a number of directions. A survey of some of these can be found in Nelson 1995.

In this chapter we intend to deal with the basics of a formal evolutionary approach to technical change, economic dynamics and growth. In so doing we will leave out for the most part the burgeoning new areas of application of evolutionary ideas to game theory, learning dynamics and bounded rationality, organization theory, financial markets, industrial organization, and the interface of economics, law and culture, most of which are dealt with elsewhere in this volume. Instead we will concentrate on a restricted class of interrelated models of growth and dynamics to see whether a viable alternative paradigm to the mainstream, neoclassical approach, as well as a new class of insights, are emerging.

There are essentially two reasons for believing that an evolutionary approach is applicable to economics. One is based on analogy and an appeal to the type of explanation common in biology: that forms of competition, innovation, variation and selection have analogues in the two subjects and thus that similar reasoning can profitably be applied in the nonbiological domain. Here most authors stress that the

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analogy should not be taken too seriously, so that it is useless to search for whatever corresponds exactly to genes, sexual reproduction, crossover or mutation in the economic sphere. Moreover, discredited forms of evolution such as Lamarckianism, the inheritance of acquired characteristics, may be perfectly conceivable in the socioeconomic realm.

The second takes a more universalist perspective. It argues that, just as biological evolution has passed through distinct stages (prokaryotic and eukaryotic life, asexual and sexual reproduction, as well as a prebiotic stage), so modern industrial society is just a distinct stage of this single process, subject to the same underlying laws if constrained by specific features of its current realization. Thus economic evolution would be an intrinsic component of a larger evolutionary process, and not merely something accidentally amenable to certain forms of reasoning by analogy.

What reasons might we have to believe this? Lotka (1924) proposed the concept of "energy transformers" to capture the common thermodynamic features of all life forms. This is quite similar to what later was termed dissipative systems (Nicolis and Prigogine 1977), i.e., thermodynamically open systems, far from equilibrium, which maintain a high state of internal organization by importing free energy from their environment, consuming it for purposes of self-repair and self-reproduction, and exporting the resulting waste as high entropy back to the environment. Thus the apparent paradox of life, already pointed out by Henry Adams (1919), of complex structure emergence in the face of the Second Law of Thermodynamics (that in thermodynamically closed systems entropy, i.e., disorder, must increase) is transcended.[1] Life (or at least carbon-based life as we know it until the industrial revolution) can be seen as a sea of such "converters" living off the waterfall of free energy flowing between the sun and the low-value infrared radiation reflected by the earth into deep space.[2]

From this perspective human civilization is distinguished from earlier forms of biological evolution by the fact that the information carriers of the selforganizing structures, rather than being encoded in a form like DNA internal to the organism, now have attained an *exosomatic*[3] (Lotka 1945) form. Information is encoded both in

[1] The observation that open systems (in particular, organisms) can seemingly circumvent the second law of thermodynamics by exporting entropy to the environment (or equivalently, importing "negentropy" or free energy, i.e., energy of a higher "quality" than the ambient heat, which can be converted to mechanical work) goes back at least to Bertalanffy (1932) and Schrödinger (1945).

[2] "Summarizing we may say that selforganization is necessarily connected with the possibility to export entropy to the external world. In other words, selforganizing systems need an input of high-valued energy and at the same time an output of low-valued energy. In the interior of selforganizing systems a depot of high-valued energy of another form is observed. The evolution processes on our planet are mainly pumped by the "photon mill" with the three levels sun-earth-background radiation (let us mention however that the geological processes are pumped by the temperature gradients between the centre of the earth and the surface). On the cosmic scale the general strategy of evolution is the formations of islands of order on a sea of disorder represented by the background radiation." (Feistel and Ebeling 1989, p. 91)

[3] There is of course another level of *endosomatic* information processing based on the neuronal system of animals, which Edelman (1987) hypothesizes to function according to neuronal group selection. This allows organisms to learn from experience during their lifetimes, i.e., is a type of acquired characteristic with clear survival value. However, until the advent of language and culture, which permit *intergenerational* transmission,

an intangible sphere existing between human minds known as culture, and a more tangible sphere consisting of writing and other forms of representation, and cultural and industrial artifacts. But the fact remains that, within the constraints imposed by the various physical substrates of information storage and transmission, evolution still must proceed along the basic Darwinian lines of (random) variation and selection. The complication associated with modern socioeconomic evolution is that we now have to deal with a mosaic of simultaneous biological (DNA), culturally tacit (existing in the human psychomotoric systems of individuals and groups) and culturally codifiable (existing in exosomatic artifacts) information transmission and variation mechanisms, the latter category being increasing machine based.

The task of an evolutionary theory of economic growth, then, might be to formulate a population dynamics of this multilevel evolutionary process, taking account both of the human components and of the increasingly sophisticated forms of artifactual energy and information transformers collectively referred to by economists in a rather undifferentiated manner as capital.[4] But even if we agree that this more fundamental perspective on economics as an integral part of the evolutionary process has a certain validity, the "genetic code" of the various non-DNA based levels still remains to be discovered. Even in biology, in fact, where a firm understanding of the molecular basis of genetics has emerged since the 1950s, many extreme simplifications of a phenomenological sort still have to be made in formal models of population genetics and evolution.[5] Thus from a practical point of view it may not make much difference whether we apply evolutionary thinking to economics as an exercise in restrained analogizing or regard the economics of human societies as a specific stage in a universal evolutionary process, until such time as canonical descriptions of the "genetic deep structure" of socioindustrial processes can be agreed upon.[6] For the time being we will have to make do with more or less plausible and heroic assumptions about the entities and variation and transmission mechanisms implicated in economic evolution, and judge them on the basis of a limited range of micro and macroeconomic "stylized facts."

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the neuronal system in itself cannot serve as a basis for long-term evolution but must still rely on the DNA substrate to generate further development.

4 This is the theme of Boulding (1978) and Boulding (1981), without the author proceeding very far down the road of formal modeling, however.

5 Thus one often assumes asexual rather than sexual reproduction to simplify the mathematics.

6 One difference, however, is the central importance placed upon energetic and environmental constraints associated with the latter perspective. These, for better or worse, will not play any explicit role in the following discussion.

Behavioral Foundations and Formal Evolutionary Modelling in the Economics of Growth and Schumpeterian Competition: Selection

Formalization of evolutionary thinking in biology began with Fisher (1930), who introduced what are now called *replicator equations*[7] to capture Darwin's notion of the survival of the fittest. If we consider a population to be composed of n distinct competing "species" with associated, possibly frequency-dependent fitnesses $f_i(\boldsymbol{x})$, where $\boldsymbol{x}$ is the vector of relative frequencies of the species $(x_1, x_2, ..., x_n)$, then their evolution might be described by the following equations:

$$\dot{x}_i = x_i(f_i(\boldsymbol{x}) - \bar{f}(\boldsymbol{x})),\ i = 1,\ n,\ \ with\ \bar{f}(\boldsymbol{x}) = \sum_{i=1}^{n} x_i f_i(\boldsymbol{x}).$$

The intuition is simple: species with above-average fitness will expand in relative importance, those with below-average fitness will contract, while the average fitness in $f(\boldsymbol{x})$ turn changes with the relative population weights. If the fitness functions f_i are simple constants, then it can be shown that the species with the highest fitness will displace all the others and that average fitness will increase monotonically until uniformity is achieved according to

$$\frac{d\bar{f}}{dt} = var(f) \geq 0,$$

where var(f) is the frequency-weighted variance of population fitness. Thus average fitness is dynamically maximized by the evolutionary process (mathematically, it is referred to as a Lyapunov function). This is known as Fisher's Fundamental Theorem of Natural Selection, but it should be noted that it is only valid for *constant* fitness functions. In the event of frequency-dependent selection, where fitness depends on population shares, including a species' own share, and increasing and decreasing "returns" may intermingle, multiple equilibria are possible and no quantity is *a priori* necessarily being maximized (see Ebeling and Feistel 1982 for an extensive discussion of maximal principles). The replicator equation only describes the relative share dynamics and thus takes place on the unit simplex S^n (where $\sum_{i=1}^{n} x_i = 1$), an n-1 dimensional space. To derive the absolute populations it is necessary to introduce an additional equation for the total population level. An alternative description due to Lotka and Volterra is based on growth equations for the population levels y_i (with the frequently used log-linear version on the right hand side):

$$\dot{y}_i = g_i(y) = r_i y_i + \sum_{j=1}^{n} a_{ij} y_i y_j.$$

A theorem due to Hofbauer asserts that Lotka-Volterra and replicator systems are equivalent (see Hofbauer and Sigmund 1988, p. 135).

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7 See Sigmund (1986) and Hofbauer and Sigmund (1988, pp.145-6) for a discussion of their basic form and various applications.

Most evolutionary economics models to a considerable extent consist of giving the functions f_i or g_i economic meaning in terms of market competition or differential profit rate driven selection mechanisms. The former usually defines a variable representing *product competitiveness*, which may be a combination of price, quality, deliver delay, advertising and other variables (for examples see Silverberg, Dosi and Orsenigo 1988 or Kwasnicki and Kwasnicka 1992). The latter assumes that product quality and price are homogeneous between producers (or subject to fast equilibriating dynamics compared to the evolutionary processes of interest) but unit costs of production differ, so that firms realize differential profit rates. If their growth rates are related to profits, as seems reasonable, then their market shares or production levels (corresponding to x_i and y_i in the biological models) can be described by replicator or Lotka-Volterra equations, respectively.

All of the models we will discuss in this chapter focus primarily on technical change as the central driving element of the evolutionary processes with which they are concerned. They differ considerably, however, in their representations of technology and how it interfaces with firm strategies and the market. A major distinguishing characteristic is whether technology is *capital embodied* or *disembodied*, i.e., whether changes in technological performance are primarily (though not necessarily exclusively) related to investment in new equipment or not. In the former case technical change is highly constrained by investment in physical capital (as well as possible complementary factors); in the latter case it is not and can be almost costless. Yet even on the assumption of embodied technical change, there can be important differences in formal treatments. The classical approach to embodied technical change uses the *vintage* concept going back to Salter (1960), Solow (1960) and Kaldor and Mirrlees (1962), as in essence do national statistical offices with the perpetual inventory approach to the measurement of the capital stock. One assumes that at any given time there is a single best-practice technology in which investment is made. The capital stock consists then of the vintages of past investment going back in time until the scrapping margin, i.e., that oldest vintage on the verge of being discarded due to technological obsolescence and/or wear and tear. This defines a technological lifetime of capital equipment.[8] The aggregate capital stock is a sum or integral (in the discrete and continuous time cases, respectively) over the vintages during this lifetime, and average technical coefficients (labour productivity, capital/output ratios) are the corresponding vintage-weighted sum or integrals. Vintage capital stock may be easy to compute from data, but they have two disadvantages which detract from their realism and tractability. First is the assumption of a single best-practice technology, which rules out multiple competing technologies at the investment frontier, a topic dear to the hearts of most evolutionary economist and students of innovation diffusion. This can be overcome to some extent by assuming multiple, parallel vintage structures of distinct technologies, as in Silverberg, Dosi and Orsenigo (1988). The second is that, although particularly discrete-time vintage capital stocks can be easily calculated from data, when they are embedded in a dynamic framework with endogenous scrapping they can lead to awkward mathematical complications. Delay difference or differential

[8] Except in the case in which capital is assumed to decay exponentially according to some presumed depreciation rate, in which case its lifetime is infinite, although older vintages rapidly become insignificant.

equations and even age-structured population dynamics become involved whose mathematical properties, except under extremely simple assumptions, are still poorly understood compared to systems of ordinary difference or differential equations.

An alternative implicitly exploited in the models in Metcalfe (1988), Iwai (1984a,b), Henkin and Polterovich (1991), Silverberg and Lehnert (1993, 1994) and Silverberg and Verspagen (1994a,b, 1995a,b), might be termed a *quasi-vintage* framework. Capital "vintages" are labelled by their type instead of their date of acquisition, so that the service age no longer plays any role, only the technical characteristics (although decay by type independently of age is still possible). Thus several qualitatively distinct technologies can diffuse simultaneously into and out of the capital stock. Furthermore, only ordinary differential (or difference) equations are needed to handle the quasi-vintage structure, a considerable mathematical simplification. This gain in realism and tractability is compensated for by an inability to track the vintages by chronological age, however. But quasi-vintages lend themselves more naturally to the kind of multiple replacement dynamics investigated by Marchetti and Nakicenovic (1979), Nakicenovic (1987), and Grübler (1990). And one view on evolution holds that its essence resides exactly in the sequence of such replacements (Montroll 1978), whether related to technologies, behavioral patterns, or social structures.

The disembodied side of technical change (disembodied at least in the sense that it is not representable by tangible equipment) is still even more of a black box than the embodied side. It can reside in (tacit) human skills or organizational and societal capabilities, but little is known of a very fundamental nature about how it is accumulated, stored, and refreshed. *Learning by doing* (Arrow 1962) is a standard phenomenological approach finding expression in power laws for the relationship between productivity and cumulative investment or production. Recently, it has also become central to much of the neoclassical endogenous growth literature. The effects of *technological spillovers* between competitors have also received considerable attention. One possible way of combining learning by doing and spillovers in a dynamic framework is Silverberg, Dosi and Orsenigo (1988), but nothing along these lines has been attempted in an evolutionary growth model, to our knowledge. The net effect of both of these phenomena is usually one form or another of increasing returns, such as increasing returns to adoption or agglomeration, network externalities, etc. (see Arthur 1988, 1994). Within the replicator framework this means that the fitness functions $f_i(x)$ truly depend on the frequencies $\mathbf{x}$, resulting in multiple equilibria, threshold phenomena, lockin, etc.[9]

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[9] The increasing returns phenomenon was studied by Arthur, Ermoliev and Kaniovski using the Polyaurn stochastic tool, which assumes an indefinitely increasing population to establish asymptotic results. The alternative case of a fixed population size with stochastic effects can be studied using Master equation methods (see Feistel and Ebeling 1989 and Bruckner, Ebeling, Jiménez Montaño and Scharnhorst 1994, and especially Jiménez Montaño and Ebeling 1980 for a stochastic formulation of the Nelson and Winter model). We will only make limited use of stochastic tools in the following, so that the deterministic replicator equation will serve our purposes.

Behavioral Foundations and Formal Evolution ry Modelling in the Economics of Growth and Schumpeterian Competition: Innovation and Learning

Evolution would soon come to an end were it not for the continual creation of new variety on which selection (as well as drift) can act. This is especially crucial for growth models, where the ongoing nature of the technical change process is at the fore, although other aspects may well converge to stable stationary patterns. Thus considerable attention has to be devoted to how innovation is realized by firms, individually and collectively. In principle most scholars agree that innovation should be modelled stochastically, to reflect the uncertainty in the link between effort and outcome. The details on how this is done may very considerably, however. The classical formulation is due to Nelson and Winter, described in more detail later in this chapter. Nelson and Winter lump technologies and behavioral rules/strategies together under the concept of *routines*. Since technical change is disembodied in their model, this equivalence is perhaps admissible, since a change in technique for a firm's entire capital stock requires only the expenditure necessary to undertake innovative or imitative search, not investment or training per se. While there is technological learning at the economy-wide level, firms themselves are completely unintelligent, since they operate according to given search and investment rules that cannot be modified as a result of experience. Instead, the firm is subject to selection as a consequence of the technologies it has stumbled upon. A somewhat peculiar aspect is the very literal application of Simon's notion of satisficing to mean that firms only undertake innovative search if their performance is unsatisfactory.[10]

An interesting elaboration of search activity and entry in the original Nelson and Winter model is presented in Winter (1984),[11] where firms are broken down into two types: primarily innovative or imitative. Further, the notion of technological *regime* is introduced (going back to the early or later Schumpeter) depending on whether the source of technical progress is external to the firm (e.g., from publicly available scientific knowledge bases) or from firms' own accumulated technological capabilities. These regimes are referred to as the *entrepreneurial* and the *routinized* and are exogenously imposed by means of specific parameter settings. Although firms can be of two types, neither type is capable of learning. Instead, the market is shown to select between the two depending on the technological regime. Entry of new firms also assumes a greater importance than the mere supporting role to which it is relegated in most evolutionary models, being stimulated in the entrepreneurial regime.

While learning based on selection/mutation dynamics has begun to play a major role in the evolutionary games literature (e.g., Kandori, Mailath and Rob 1993, Young 1993), very little has found entrance into evolutionary models of a general economic orientation. A first stab at changing this state of affairs for the theory of growth was

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[10] This should be contrasted with the Silverberg and Verspagen models, where firms undertake behavioral *imitation* with increasing probability the more unsatisfactory their performance is.

[11] The discussion of the model is couched in terms of *industry* dynamics, not economy-wide growth, although there is nothing in the basic assumptions to preclude analysis of the latter.

undertaken by Silverberg and Verspagen (1994a,b, 1995a,b), drawing on the evolution strategy literature (Schwefel 1995). Here mutations are local around the current strategy, and the probability of imitation is an increasing function of dissatisfaction with current performance and the size of the imitated firm. In contrast to the Nelson and Winter tradition, strategies and technologies are treated separately. The learning algorithm applies only to the firms' R&D expenditure strategies; their technological performance then follows in a somewhat complex manner from these decisions and market feedbacks. In this way it is possible to implement simple boundedly rational decision rules gleaned from actual business practice, such as targeted R&D/total investment or R&D/sales ratios, or a combination of the two.

Genetic algorithms and classifier systems have also been gaining favour in recent years as mechanisms for operationalizing learning with artificial agents.[12] Although these appeal even more directly to a discrete genetic mechanism of inheritance à la biological DNA than social scientists may feel comfortable with, they may also be employed agnostically simply as algorithmic tools to allow learning to happen, if not as models of how learning actually happens. The goal of an *artificial economics* modelling philosophy as espoused by Lane (1993) is to put together a basic web of economic interactions between artificial agents endowed with a *tabula rasa* knowledge of their environment, but fairly sophisticated abilities to learn, and see what sorts of markets, institutions and technologies develop, with the modeller prejudicing the developmental possibilities as little as possible. Something along these lines has already been implemented to a certain extent in the 'sugarscape' model of Axtell and Epstein (1995), paralleling the artificial worlds movement in the biology domain (cf. Langton 1989 and Langton, Taylor, Farmer and Rasmussen 1992). While this direction of research has generated much excitement, it has not avoided the fate of many overhyped scientific trends in the form of a sceptical backlash (see Horgan 1995). Be that as it may, in the following we will limit ourselves to those models rooted in the economics tradition that promise to address issues of long-standing empirical interest.

An Overview of Evolutionary Growth Models

In this section, we will discuss the similarities and differences between several growth models that have been developed over the last decades, and which were based upon the evolutionary principles that we have outlined so far.[13] The first model that will be discussed is the one presented in Nelson and Winter (1982). This model can be seen as the first evolutionary growth model, and, as will be shown in the rest of the discussion, can be regarded as the pioneering effort in the field. The Nelson and Winter model is a

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[12] See Booker, Goldberg and Holland (1989), and Goldberg (1989) for basic theory and methodology and Holland and Miller (1991), Kwasnicki and Kwasnicka (1992) and Lane (1993) for some economic applications.

[13] The papers that we discuss by no means form an exhaustive list of 'evolutionary growth theories'. However, limiting ourselves explicitly to papers in which mathematical models with a clear 'population perspective' are the core of the analysis, we hope that the present list covers at least the most prominent contributions.

model with an explicit microeconomic foundation, which consists of modelling the behaviour of firms in their search for more advanced techniques. Basically because of the complexity arising from the simultaneous existence of multiple firms with different search behaviour and, hence, different technological levels, the Nelson and Winter model is analyzed by means of computer simulations.

One class of more recent growth models in the evolutionary tradition follows the Nelson and Winter perspective of adopting a microeconomic foundation. Consequently, these models also resort to computer simulations for analysis. In this group of models, the main contributions are to extend the original Nelson and Winter setup by introducing more realistic representations of technology, to extend the analysis to a multi-country framework, or to extend evolutionary principles to the issues of behavioral strategies, instead of just technological change.

A second broad group of evolutionary growth models does not take the explicit microeconomic perspective proposed by Nelson and Winter, at least not in the sense of modelling the individual firm. Consequently, the similarities to the original Nelson and Winter model are less pronounced in this group of papers. The main reason for not taking into account the microeconomic foundations explicitly, seems to be the desire to keep the models analytically tractable, or to keep the complexity of a simulation model within bounds, so that extensions to, for example, a multi-country context, or more systematic analysis of the closed economy case, becomes easier.

Because this second group of papers does not have clear roots in any specific approach, these contributions are necessarily more heterogeneous than those of the first group. Still, it is possible to find two broad approaches here. The borderline between the two subgroups is the distinction between analytical solutions and computer simulations.

The guidelines for our discussion of these different approaches within the field of evolutionary growth theory will be four different points. The first three of these points correspond to the three basic principles of the evolutionary process that we have discussed: heterogeneity of the population (usually firms, or alternatively countries, or techniques), the mechanism for generating novelty in the population (mutation, usually in the form of technical innovations), and, finally, selection (related to the economic environment in which the population operates). The last point we will discuss is the economic interpretation, or outcomes of the models.

The Nelson and Winter Model

We start our discussion with a brief summary of the model presented in Nelson and Winter (1982, Part IV), which can be regarded as the pioneering effort in the field of evolutionary growth models.[14] This model (the NWM for short) will be used as a benchmark case in the rest of this paper.

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14 The discussion in Nelson and Winter (1982) largely focuses around an earlier article by Nelson *et al.* (1976).

In the NWM, heterogeneity is defined in terms of firms. Firms use production techniques which are characterized by fixed labour and capital coefficients (a_L and a_K, respectively). Output is homogeneous, so that we have a pure model of process innovation.[15] Thus, firms produce using a Leontief production function, which does not allow for substitution between labour and capital. Over time, technical change may be biased (i.e., changes in a_L and a_K are not proportional), so that a phenomenon that resembles substitution between labour and capital may result (this is a key result in the outcomes of the model, so that we will come back to this below).

The generation of novelty occurs as a result of search activities by firms. Search is undertaken in a (given and finite) pool of existing techniques (i.e., combinations of a_K and a_L). At any point in time, some of the techniques available in the pool are known, while others remain to be found in the future. Search activities are determined by satisficing behaviour, i.e., firms only engage in search if their rate of return falls below an arbitrarily set value of 16%. The mutation or search process may take two different forms: local search or imitation. In the first case, firms search for new, yet undiscovered techniques. Each undiscovered technique has a probability of being discovered which linearly declines with a suitably defined technological distance from the current technology (hence the term *local* search). By varying the skewness of this distance function either labour or capital bias can be introduced into the search process. In the second search process, imitation, a firm searches for techniques currently employed by other firms but not yet used in its own production process. Thus, this aspect of the search process does not generate novelty in the strict, aggregate sense. Rather, it produces novelty at the microeconomic level. The probability of success in imitation is proportional to the share in output of each technique.

Given that a firm engages in search (i.e., that its rate of return is smaller than 16%), it can only engage in one type of search. Which type of search is being undertaken is a random event, with a fixed probability for each type. If the search process is successful, i.e., if the firm finds a new technique, it adopts this new technique only if the expected rate of return is higher than its present rate of return. Expectations are subject to error with regard to the true values of the capital and labour coefficients.

An additional source of novelty in the economy is entry by firms which were not engaged in production previously. This is conceptualized by "empty" firms, with a capital stock equal to zero, but which are active in the search process. If such an "empty" firm discovers a production technique which promises a rate of return over 16%, there is a 25% probability that it actually enters the market. If entry occurs, a value for its capital stock is drawn randomly.

The selection process is thus largely driven by the rate of return on techniques. This rate of return depends on the (real) wage rate, which is a function of exogenous labour supply and endogenous labour demand. The latter is a function of output, which, in its turn, depends on the capital stocks and the techniques currently employed. Net investment in capital is equal to firm profits (minus a fixed fraction that it must pay as

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15 Gerybadze (1982) has extended the NWM to the case of product innovation.

dividends) minus depreciation (at a fixed rate). Insufficient profits lead to negative investment, i.e., firms which make losses see their capital stock shrink. Thus, selection takes place simultaneously on firms and production techniques, where one may think as firms as the phenotype, and techniques as the genotype.

Like most models we will discuss here, the NWM has to be simulated on a computer to obtain an impression of its implications. The model, which is calibrated for the case of the Solow (1957) data on total factor productivity for the United States in the first half of the century, yields an aggregate time path for the variables capital, labour input, output (GDP), and wages (or labour share in output). The analysis in Nelson and Winter (1982) is confined to 16 runs, in which four main parameters (the localness of innovation, the emphasis on imitation search, dividends, and the labour saving bias of local search) were varied between a high and a low state.

Nelson and Winter primarily address the question whether these time series correspond in a broad qualitative sense to the ones actually observed by Solow. Given the affirmative answer to this question, they argue at length that "it is not reasonable to dismiss an evolutionary theory on the grounds that it fails to provide a coherent explanation of ... macro phenomena" (p. 226). More specifically, it is argued that although both the neoclassical explanation of economic growth offered by Solow (as well as later work in this tradition) and the NWM seem to explain the same empirical trends, the underlying causal mechanisms between the two perspectives differ greatly:

> the neoclassical interpretation of long-run productivity change ... is based upon a clean distinction between 'moving along' an existing production function and shifting to a new one. In the evolutionary theory ... there was no production function. ... We argue ... that the sharp 'growth accounting' split made within the neoclassical paradigm is bothersome empirically and conceptually. (Nelson and Winter 1982, p. 227).

Looking below the surface of the broad qualitative resemblance between the simulation and the actual empirical data, Nelson and Winter arrive at some interesting conclusions with regard to the effects of variations in their four parameters. They find that decreasing the localness of search leads to higher values of technical change, a higher capital-labour ratio and lower market concentration. Search biased towards imitation of other firms (rather than local search for new techniques) leads to a higher capital-labour ratio, and lower concentration. Higher capital costs (dividends) lead to lower technical change and a lower capital-labour ratio. Finally, labour saving technical change leads to a higher capital-labour ratio. All of these effects (which were established by regressions on the simulation results) have some plausible explanation from the point of view of the evolutionary theory provided by Nelson and Winter.

Thus, the NWM seems to provide two sorts of outcomes. First, there is the 'mimimalistic' point of view that an evolutionary model may explain the macro facts about economic growth on the basis of a 'plausible' microeconomic theory (i.e., a theory which can account for the observed heterogeneity between firms at the micro level).[16] While this a useful result, there are at least two reasons why one should not be satisfied with it as the sole basis for further development of evolutionary growth models. First, a more 'positive approach' to scientific development would require an evolutionary theory to provide fresh results of its own and not only benchmark itself against neoclassical results, even if the latter have dominated economic discourse until now. Second, the empirical validation of the NWM is highly specific to a single dataset, i.e., the one used by Solow. After the events of the 1970s (such as the productivity slowdown, or productivity paradox), the stylized facts about economic growth that were predominant in the period when Nelson and Winter formulated their model are no longer uncontested.

The second type of result of the NWM, i.e., the relations between the four main parameters in the model and the macroeconomic predictions, can be seen as a first attempt at a more 'positive' approach. But perhaps more important than these results, which only play a minor role in the exposition, is the paradigmatic function of the model as such. As we will see below, the NWM has set the stage for a number of more elaborate evolutionary models capable of analyzing economic growth as an evolutionary process, using much more refined assumptions and model setups, and arriving at conclusions that go beyond broad similarity to the 'stylized facts' developed in the 1950s. Some of the ways in which these newer models refine the NWM concern the endogenization of the mutation and imitation process, the extension of the model to one in which firms in different countries interact, or in which there are input-output relations between firms. The common roots of most of these models in the NWM is evident, however.

Evolutionary 'Macro Models'

Perhaps the most important aspect of the NWM is its explicit microeconomic foundation. As was argued above, this seems to be the basis for the most important conclusion regarding the outcomes. Among the evolutionary growth models inspired by the NWM, there are models with an explicit microfoundation, but also models formulated only at the macroeconomic level. The discussion here will start by outlining the latter category. The microeconomically founded models will be discussed in the following subsection. The models considered in this subsection are Conlisk (1989) (CON), Metcalfe (1988) (MET), Verspagen (1993) (VER) and Silverberg and Lehnert (1993, 1994) (SL).

The first two of these models can be solved analytically, whereas the last two follow Nelson and Winter in using computer simulations for analysis. The analytically solvable models necessarily have to make extensive simplifications relative to the rich picture of the NWM that has become somewhat of a standard for the second group of

[16] See also Nelson (1995) for an extensive argument along this line. The fact that growth accounting with an aggregate production function can lead to a deceptively high goodness of fit even with a microeconomy of heterogeneous firms inconsistent with aggregation or even absurd underlying production functions has been pointed out repeatedly in the literature. See Houthakker (1956), Phelps-Brown (1957), McCombie (1987), Shaikh (1974, 1980, 1990), Simon and Levy (1963), and Simon (1979).

evolutionary growth models discussed below. In the case of the Conlisk model, these simplifications go so far that it is arguable whether or not the model is still a truly evolutionary one. As will be shown below, however, some of the most important assumptions and results of evolutionary theory remain in the Conlisk model, so that we have no hesitation to discuss it here alongside other models. The abstractions necessary to yield analytical solutions should not be regarded in a dogmatic way leading to the exclusion of these models from the evolutionary category. It is in the interests of the discipline to explore the boundaries of what is analytically possible while at the same time exploring more complex models by means of simulation techniques.

The assumptions on the role of heterogeneity in the CON, MET and SL models are quite similar. In all three models, production techniques are the most basic entities. These techniques differ with respect to their technological levels, for which labour productivity is the sole indicator. This is the main source of the heterogeneity on which selection operates. In the VER model, heterogeneity occurs between sectors within countries, i.e., the sector is the smallest unit of analysis. Sectors differ with regard to the product they produce, which might have different income elasticities in different countries, and also with regard to labour productivity, as an indicator for technology.

The way in which novelty is generated varies the most in the models in this group. The simplest approach is found in the MET model, where novelty is assumed to be absent. To keep the model tractable, the analysis is confined to the selection process operating upon a given set of techniques. Only a little more advanced is the assumption in VER, where technical progress is purely deterministic, and specified in the form of a 'Kaldor-Verdoorn' type of process, which stresses learning-by-doing and dynamic scale economies. Basically, a higher output growth rate leads to faster productivity growth, although the 'returns' to output growth in this process are diminishing.

More squarely in the evolutionary tradition are the novelty generating processes in CON and SL. In these models, a stochastic mechanism is at work in which new techniques are generated from a random distribution. In CON, this is a normal distribution of labour productivity increments with a positive mean, whereas in the SL model, innovations arrive according to a time-homogeneous or inhomogeneous Poisson distribution. In the latter case, whenever an innovation occurs, the new production technique is assigned a labour productivity equal to $(1+a)$ times the prevailing best practice technique, where a is an endogenously fixed constant.

Selection is crucial in all models in this group. In this case, the simplest representation is provided by the CON model. Here, there is a ranking of techniques according to their productivities.[17] At any point in time, the search process is based upon the first n techniques in this ranking: the mean of the distribution from which new techniques are

[17] Conlisk's techniques can be ranked in two different ways. The first is by means of their actual productivities at any point in time. Because labour productivity partly depends on capital depreciation in this model, the labour productivity of a technique varies over its lifetime. Techniques can also be ranked on the basis of their productivities at the time of invention. This is the relevant way of ranking in the rest of the discussion here.

drawn is a weighted mean of these first n techniques. This means that "[s]ince new plant technology will build on the innovative plants from the past rather than on the average plants of the past, productivity will grow. In the absence of randomness, all plants would be alike; hence there would be no innovative plants to induce growth. Thus, randomness is essential." (Conlisk 1989, p. 794).

In the VER model, the selection mechanism is represented by a replicator equation in which sectors from different countries compete with each other on the basis of production costs (profits are assumed to be zero). Production costs are a function of the technological level of the sector, the wage rate, and the exchange rate. Wages depend upon productivity growth and the unemployment rate, and exchange rates adjust slowly to achieve purchasing power parity between nations in the long run. There is no explicit economic basis for the replicator equations other than a short reference to the idea that consumers (in the absence of quality differences between producers) prefer those products with the lowest price, and that adjustment to these long-run preferences is slow. At the aggregate level, selection in the VER model is a function of sectoral shares in total consumption, which evolve according to different real-income elasticities in different countries.

Finally, the selection mechanisms in the SL and MET models are quite similar. In these models, the replicator mechanisms result from explicit economic theorizing. In both models, profits are the driving force for selection. Confronted with economy-wide wage and output price levels, techniques with different levels of labour productivity will yield different profit rates. The assumption is that profits are reinvested in the same technique[18], so that the share in productive capacity of techniques with above-average productivity increases.

In the SL model, real wages are a function of the unemployment rate, and effective demand does not play a role (production is always equal to productive capacity). This leads to a model which is essentially a multi-technique version of Goodwin (1967). This model, in turn, is the standard economic example of a predator-prey model, and yields the same outcome as the original Lotka-Volterra model. In the MET model, nominal wages are given, while the price of output is found by confronting demand and supply. The demand curve is given exogenously, whereas the supply curve is found by aggregating over the different production techniques, which are assumed to supply all their output at the cost level determined by the wage rate and labour productivity. The price of output is found at the intersection of the demand and supply schedules. All techniques with cost levels higher than the current output price are assumed to be scrapped from the market. New techniques enter at the lower end of the supply schedule, and thus achieve high profit rates.

Despite the similarities in model setup in this broad group of 'aggregate' evolutionary models, there is not much similarity between the outcomes of the different models. Under the assumption that technology advances are indeed random (see above),

[18] In fact, in the SL model, a certain fraction of profits is redistributed towards the more efficient techniques. Hence, more advanced techniques attract a more than proportional share of total profits. This is, however, not essential to the working of the selection process, although it tends to speed up selection.

Conlisk shows that the growth rate of the aggregate CON economy is a function of three variables: the standard error of the productivity distribution of new plants (which can be interpreted as the average innovation size), the savings rate (which is defined somewhat unconventionally), and the speed of diffusion of new knowledge. Moreover, by changing some of the assumptions about the specification of technical change, the CON model emulates three standard specifications of technical change found in growth models in the neoclassical tradition. In this case, the first and third factor no longer have an impact on growth (they are specific to the 'evolutionary' technical change specification of the model). However, the impact of the savings rate can be compared between the various model setups. Conlisk finds that using purely exogenous technical change (as in the Solow model), or learning by doing specifications as in the model by Arrow (1962) or Romer (1986), the savings rate does not have an impact upon (long-run) economic growth. This result, which is in fact also well known from standard neoclassical growth theory, marks an important difference between these models and his more evolutionarily inspired specification.

The other analytical model discussed in this section, the MET model, does not aim at deriving such specific results. Instead, the aim seems to be to provide an exposition of the workings of a possible selection mechanism on the growth pattern of an open economy. Due to the many simplifying assumptions that are necessary to arrive at an analytical solution (such as the constancy of countries' shares in world demand, and fixed nominal wages and exchange rates), it is not easy to link the results to actual empirical trends. Nevertheless, the model clearly shows how a country's share in world demand and its technological level shape the interaction between the trade balance and the growth rate of the economy. The model is thus clearly one in which growth depends on openness and competitiveness of the economy. The long-run outcome of these forces is that the share in world production of the technologically most advanced country tends to one, although production in the more backward country may still be positive. Moreover, applying comparative statics, the model predicts the effects of events such as currency devaluations or protective tariffs.

The VER model can be seen as an attempt to analyze the same issues as in the MET model, but here the emphasis is more on the long-run dynamics of technical change, wages and the exchange rate, rather than on the adjustment process. Verspagen uses simulations to analyze the effects of differences in technological competence between countries, or differences in demand patterns between countries. Because the model is multi-sectoral, endogenous specialization patterns arise, and countries' technical performances depend upon their specialization. These differences in technological competitiveness in turn have an effect upon unemployment and the wage rate, which again feeds back upon competitiveness. In essence, this model highlights the interaction between specialization and growth, and the outcomes show that in a world in which there are differences between technological potentials of sectors and countries, growth rate differentials between countries may be persistent, although not exactly predictable (due to the nonlinear nature of the model).

The SL model predicts a complex pattern for the rate of technical change in which long-run fluctuations of a $1/f^{\alpha}$-noise character dominate, although the stochastic input is simple white (Poissonian) noise. The time series for technical change and growth generated by their simulations are analyzed by means of spectral analysis, in order to decompose them into harmonic oscillations of various frequencies. The result is a downward sloping linear curve in a plot of the log of spectral density *vs.* the log of the frequency of the oscillations, known as $1/f^{\alpha}$-noise, and is interpreted by Silverberg and Lehnert to be a form of long or Kondratiev waves which are neither strictly periodic nor a random walk. In fact, they show that these series have characteristics of deterministic chaos, allowing more precise short-term prediction than a random series would warrant. They term this finding 'evolutionary chaos'. Moreover, technological replacement shows the same robust pattern of successive logistic diffusion into and out of the economy as has been repeatedly revealed in the empirical literature.

Summarizing, perhaps the most important common factor in these models is the role of technological differences between sectors, technologies or countries. These differences are continually modified by a selection process which, no matter how specified, is the driving force for economic growth in all four approaches. It is clear that although these models share a number of general evolutionary principles in their approach to the issue of economic growth, there is no standard set of assumptions, nor does a common set of results emerge.

Evolutionary 'Micro Models': in the Footsteps of the NWM

We continue our discussion of recent evolutionary models of economic growth by considering a number of models resembling the original NWM in the sense that they are rooted in an explicit microeconomic theory of firm behaviour. Once again, the discussion will be organized around four themes: heterogeneity, the generation of novelty (mutation), selection, and the economic outcomes of the analysis. We will discuss models by Chiaromonte and Dosi (1993) (CD), Dosi *et al.* (1994) (DEA) and Silverberg and Verspagen (1994a,b) (SV).

All three models follow the NWM in assuming that technological differences are the prime source of heterogeneity between firms. They also follow the NWM in adopting process innovation as the sole form of technological progress, and thus use the labour and capital coefficients to characterize technology. SV adopt the formalism for dealing with capital-embodied technical change (which we termed the *quasi-vintage* structure above) from SL and assume that each firm may apply a number of production technologies at any point in time. In the CD and DEA models, a firm is characterized by a single labour coefficient. DEA explicitly take an open economy perspective with firms operating in different sectors and different countries (characterized primarily by different labour markets and exchange rates). The firms are located in a home country, and when they serve a market in a different country, the flow of goods is counted as exports.

All three models potentially allow for a second source of heterogeneity in the form of behavioral differences between firms. In SV, these behavioral differences are the R&D strategies, whereas in DEA and CD, the firm strategies may also extend to decisions on price setting (markups), although no systematic study of the effects of heterogeneity or of selection on these strategies is undertaken. In CD, the pricing strategy is based upon demand expectations, which may also vary between firms. The firms in these models are thus characterized by their technological capabilities (in the form of input coefficients), and by economic strategies, which determines how much resources they invest in the search for new technologies, or how they price their products.

In the NWM, local search and imitation were the two means by which firms could generate novelty. This is where the newer models discussed here start expanding on the original NWM approach. In CD, the search process takes place in a complicated two-dimensional space. One dimension in this space corresponds to 'typologies', or 'technological paradigms', and is formally defined as the labour coefficient of producing a unit of productive capacity of a certain type. Within each of these typologies, the labour coefficient for producing a homogeneous consumption good by means of the unit of productive capacity defines the other dimension in the two dimensional space. In CD, firms either produce 'machines' (each of which is characterized by a set of coordinates in the two dimensional plane), or they produce consumption goods (i.e., they use machines as inputs). The evolution of the plane itself, as well as the specific trajectories realized by individual firms in the plane, is a complex stochastic process depending on a number of assumptions with regard to the cumulativeness of technology as well as the realized history of the model.

In DEA, the search space is more similar to the one in the NWM, with the probability of an innovation depending on R&D employment, and the productivity improvement in the event of an innovation also being a random event. In CD, the innovation process differs between the two sectors in the economy. In the first sector, which produces capital goods, the success of innovation is determined by a similar stochastic procedure to DEA, i.e., success depends on the number of R&D workers. When successful, the new capital good's productivity is drawn randomly. In the consumption goods sector, firms possess a skill level for each available capital good type. This skill level evolves by a learning process, which has both public and private features (i.e., a firm using a certain type of capital good improves its own as well as the publicly available skill of working with this machine). Firms are not able to predict their skill level precisely but rather under or overestimate this level by some systematic value. Actual labour productivity is a function of the capital good's characteristics and the firm's skill level. Firms in the consumption goods sector maximize a function involving labour productivity, prices, and the order backlog, and thereby choose which capital good they want to use.

In SV firms may also invest in R&D, and the probability of innovation depends on their R&D effort. When an innovation is made, it is introduced as in SL. Firms that are behind the economy-wide best practice frontier have a higher probability of making an innovation (i.e., adopting the next technology, which brings them closer to the frontier but does not advance the latter itself) than would be the case if they were currently on the frontier. This reflects the diffusion of technological knowledge between firms, i.e., technological spillovers. However, they still assume that this form of technological catchup requires R&D investment of the backward firms and is thus not costless. The main difference between SV on the one hand and DEA and CD on the other hand is that the former allows for the evolution of the R&D strategies themselves, in other words, behavioral learning. In CD and DEA, a firm's R&D and price strategies remain fixed for its entire lifetime. In SV, there are actually selection, mutation and imitation processes with regard to these strategies, so that evolution takes place at two levels.[19] It is assumed that firms have a (small) probability of changing their R&D strategies every period (mutation of strategies). If this occurs, the firm adds a random increment to its present strategy, where the increment is drawn from a normal distribution with mean zero. Thus, mutation of strategies is a local process, with a low probability for the firm to make large jumps in parameter space. There is also a variable probability that a firm imitates the R&D strategy of another firm. This probability decreases with a measure of firm success, the firm's growth rate, so that laggard firms are more likely to imitate than successful ones (to reflect satisficing behaviour). Which firm is imitated is also a random process, with the probability of being imitated equal to market share. In DEA, the probability of innovation depends on the number of past and present R&D workers. A successful innovation increases firm-wide productivity by a random step.

Selection takes place according to a replicator process in all three models. In SV, the process is essentially the same as in SL (discussed above), which means there is a Phillips curve determining the real wage rate, and firms expand their productive capacity at a rate equal to their overall (averaged over technologies) profit rate. Thus, there is a predator-prey process in which more efficient technologies tend to extend their market share, and thus firms applying these technologies will grow faster. Exit of firms occurs whenever their market share falls below a threshold, and a new firm with random characteristics enters the place of the old firm.

In CD and DEA, the selection process is represented by a replicator equation which is not specifically founded in any theory, as in the VER model discussed in the previous section. Prices and exchange rates (in DEA) are the variables determining competitiveness in these models. Thus, technological competences (labour productivity), aggregate characteristics of the economy such as wages, as well as other behavioral variables (pricing rules) enter directly into competitiveness. In CD, competitiveness of a firm also depends on the backlog of orders (i.e., unfulfilled demand in the previous period). The market shares following from the replicator equation are translated into actual production levels by considering the size of the aggregate market, which is endogenous to the model. The total size of the market is the minimum of aggregate demand and supply.[20] Aggregate demand is found from the

[19] In Silverberg and Verspagen (1995a), firms are characterized by a combination of two different R&D strategies: one targeting the R&D to total investment ratio, and one targeting the R&D to sales ratio.

[20] Neither CD or DEA discuss very extensively what happens when supply falls short of demand.

total wage bill (the consumer goods sector in DEA and CD), or total firm demand for machines (the capital good sector in CD).

SV provide a relatively systematic, although by no means complete, search of the parameter space of their model. They arrive at three different types of results. First, they find that for sufficiently high values of technological opportunity (which links the R&D to capital ratio of the firm to the probability of innovative success), firms tend to converge after a considerable adjustment period to a common R&D strategy.[21] In this long-run evolutionary equilibrium of the system, R&D strategies converge to well-defined values (around which the system fluctuates randomly) quite comparable to values observed in high-tech industries in advanced countries. The growth rate of the economy in this state is characterized by the same $1/f^{\alpha}$ noise pattern found in SL. Second, SV find that after initializing the economy with zero R&D strategies, convergence to the equilibrium strategy takes the economy through different growth phases. These phases are characterized by different R&D levels, growth rates, and market concentration patterns in the following sequence. The economy starts out in a low R&D, low technical progress, and near monopoly regime (with the monopoly firm being replaced by a different firm at more or less regular intervals). After passing through a state of intermediate values for all variables, the long-run R&D equilibrium is characterized by low concentration (a nearly even size distribution of firms) and a high rate of technical change. Finally, SV find that by varying such parameters as technological opportunity, R&D spillovers and mutation and imitation rates of the R&D strategies, there are systematic variations in the level of technical progress and market concentration consistent with economic intuition.

The discussion in DEA and CD is less systematic, and does not arrive at clear-cut relations between the parameters values and the outcomes of the model. In fact, CD do not provide results for more than one particular run, and DEA provide very little information about alternative runs. Neither of the two papers provides systematic summary statistics for multiple runs, whether for different parameter sets or identical parameter sets with different random seeds.[22] Keeping the 'preliminary' nature of the results in mind, the following seems to be the main outcome of the CD model. In the Nelson and Winter tradition, they put much emphasis on the interpretation of their results as empirically plausible, yet rooted in a more sophisticated microeconomic foundation (compared to mainstream theory):

> ... one can only say that the generated series of income and average productivity seem 'plausible' (...): we conjecture that the aggregate dynamics might show econometric properties similar to those empirically observed. As with 'real business cycle models', one cannot distinguish between transitory (cyclical) and permanent (trend) components in the generated time series. However, unlike

[21] This should be compared with the analogous results from neoclassical endogenous growth theory such as Aghion and Howitt (1992).

[22] DEA state that "the results that we shall present appear to be robust to rather wide parameter variations" (p. 235), without presenting statistics to support this statement, or specifying how "wide" the variations actually were. CD, discussing one particular outcome, state that it "holds across most of the simulations that we tried" (p. 58).

> the former models, innovations do not take the form of exogenous stochastic shocks but, rather, are generated endogenously by agents themselves. (p. 56)

Thus, it seems as though the evolutionary model has evolved (from NWM to CD) as has the 'adversary mainstream' model (from the Solow model to the real business cycles and endogenous growth models), but nothing else has changed.

While DEA put some emphasis on this property of their outcomes, their main interest relates to growth rate differentials between countries. They find that for the 55 countries in the particular runs for which results are presented, there is a significant trend for GDP per capita levels to diverge. This is tested by using a linear functional form that relates the growth rates of GDP per capita to the initial level of this variable. A significantly positive slope is found. Applying a 'post-selection bias' and testing only for those countries which at the end of the period turn out to be developed, they obtain a negative coefficient (pointing to convergence), which is, however, not statistically significant.[23] Given the available empirical evidence for long time periods and large cross-country datasets, it is not clear whether this property of the simulated data is in close correspondence with reality. Most authors in the field of empirical 'convergence' have found significant convergence for a group of relatively advanced economies in the 1950-1973 period. Divergence seems to prevail in a larger sample of countries (including, e.g., the African countries). It is also clear that convergence in the relatively rich group of countries was much weaker, if present at all, in earlier periods.[24] Thus, it seems as if the DEA results are (at least partly) compatible with a particular period in time (pre-WW II), but not necessarily so with the strong post-war convergence period observed in the OECD.

Evolution, History and Contingency as the Driving Forces of Economic Growth: an Attempt at a Synthesis

Having outlined the assumptions and results of a number of contributions to 'evolutionary growth theory', it is time to ask whether this discipline has added to our understanding of the phenomenon of economic growth. We have already seen that the results of many evolutionary growth models are not very specific in the sense that they do not provide insight into exactly which factors play which role in the growth process. Compared to other approaches in growth theory, such as the neoclassical model with its highly practical 'toolbox' of growth accounting, it might seem at first glance as though not much could be learned from their evolutionary alternatives.

As was already stressed by Nelson and Winter (1982), it is indeed one aim of evolutionary models to demonstrate that the sense of precision offered by the mainstream models is to some extent illusory. The causal relationships between the main variables in these models, Nelson and Winter argue, are not so clear once one

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23 This experiment seems to be derived from DeLong's (1988) critique of Baumol (1986) who, as did many other authors before and after him, estimated the convergence equation tested by DEA.

24 See, e.g., Verspagen (1995) for further characterizations of the convergence debate.

adopts a microeconomic framework in which heterogeneous firms, disequilibrium, and bounded rationality are the key ingredients. The implications of this point of view may certainly be far reaching. The importance of this argument resides perhaps not so much in the critical attitude towards mainstream theory as in the argument that models of economic growth are just not able to make precise predictions on the basis of exact causal relations. This idea is quite well illustrated by a quotation from Nelson (1995, p. 85-6):

> "There is no question that, in taking aboard this complexity, one often ends up with a theory in which precise predictions are impossible or highly dependent on particular contingencies, as is the case if the theory implies multiple or rapidly shifting equilibria, or if under the theory the system is likely to be far away from any equilibrium, except under very special circumstances. Thus an evolutionary theory may not only be more complex than an equilibrium theory. It may be less decisive in its predictions and explanations. To such a complaint, the advocate of an evolutionary theory might reply that the apparent power of the simpler theory in fact is an illusion .... Such a framework would help us see and understand better the complexity of the economic reality .... But it will not make the complexity go away."

Nelson thus seems to argue that we must simply accept as a fact of life the inability to predict and precisely explain that characterizes many of the evolutionary growth models outlined above. Although we sympathize with this line of reasoning in general, we wish to argue that there are indeed ways in which evolutionary growth theory can take up Nelson's gauntlet of 'complexity' in a more positive way. We suggest going back to an old discussion in evolutionary biology, which focuses on the interaction of 'chance and necessity'.

This debate, which was stimulated by Monod (1970), inquires into the consequences of adopting a view of evolution in which random events, such as genetic mutations, or random changes in the selection environment (such as the by now famous meteorite which supposedly led to the extinction of dinosaurs on earth) have an impact on the general characteristics of 'life as we know it'. In the words of Gould, the question is whether the biological diversity on earth would be different if 'the tape were played twice'.[25] As far as chance and contingency are concerned, the answer to this question would be a firm yes: if evolution completely depended on random events, a literally infinite number of natural histories would be possible, and there is no reason why any of them would turn up more often than others in imaginary experiments.

Applying the analogy to economics and the history of technology, the question is if the tape were played twice, would textile innovations and mechanical power be the technological stimulus for an industrial revolution, and, if so, would England again be the place of origin of such a revolution? Taking this reasoning a step farther, would a Great Depression always occur, and would the equivalent of the USA always surge to

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[25] See Fontana and Buss (1994) for a discussion of Gould's question in the context of an abstract evolutionary model of self-organization.

economic and technological dominance, inducing a period of sustained catch-up and convergence in part of the world after the second World War?

The economic historian's explanation for such events rests on specific historical circumstances not obviously connected to a more general causal mechanism extending across time periods. For example, Maddison (1991) points to specific institutional and policy factors that led to a succession of growth phases in the modern world since 1820. Although Maddison does not discuss the causal mechanisms underlying these factors at great length, it is obvious that there is a considerable degree of contingency associated with these factors, making them hard to explain from an economic point of view.

However, the biological discussion also highlights the role of more systematic factors in the evolutionary process, suggesting the hypothesis that some 'histories' are more likely than others. Taking this argument even further, Fontana and Buss (1994), on the basis of simulation experiments, have argued that there are certain characteristics of biological life that seem to be generic and robust to different randomizations of the model. They argue that "these features ... might be expected to reappear if the tape were played twice" (p. 757). Hence the dual relationship between 'chance' and 'necessity', which leads to a world view in which there is considerable uncertainty with regard to exact outcomes and causal mechanisms, but in which there is also some limit to the randomness of history. Thus the basic SV model and its derivatives point to a definite value of R&D, and distinct preferences for particular strategic routines over others, as an emergent outcome of this process of chance and necessity. In fact, the stochastic component of learning models can actually reduce the number of possible outcomes as compared to the equivalent deterministic one (Foster and Young 1990, Young 1993).

The evolutionary growth models we have discussed almost all rely upon stochastic technical change as the driving force of economic growth. In many of the models, one outcome of this stochastic process after a selection process has acted upon it is that a wide range of 'economic histories' are possible, some of which seem to be compatible with the 'stylized facts' of actual empirical observations. While these results are often used to argue the 'minimalist' position that an evolutionary theory can explain the phenomena explained by mainstream theory but with a more realistic (Nelson 1995, p. 67) microeconomic foundation, we wish to argue that this approach should be extended along the lines suggested by the debate on 'chance and necessity' in biology.

Viewed this way, evolutionary growth models would have to be more precise on the possible range of outcomes they predict, by outlining the general features of the histories generated in the simulation experiments. For example, in a model of international growth rate differentials as suggested by DEA, the main question would be under what circumstances a fairly 'narrow' bandwidth of outcomes would exist, for example in the sense of a small range of values for the coefficient of variation of per capita GDP in the different countries. Such an approach would admittedly not help us much in understanding specific events in economic history. It would not give us an answer to the question why the industrial revolution took place in England, or why the productivity slowdown occurred in the mid-1970s. However, given the inability of evolutionary theory to identify clear-cut causal mechanisms explaining these facts, it would certainly provide a powerful tool of analysis, which would take the field a step ahead of the currently available results.

In an extension of the SV model to the international economy we have taken a first step in trying to establish results along these lines (Silverberg and Verspagen 1995a). There we show that one only needs a fairly simple set of assumptions to robustly generate artificial time series of international economic and technological leadership similar to those observed empirically. We argued that this exercise, although still of a preliminary nature, shows that historical events such as the postwar catch-up boom can be seen as broadly compatible with an evolutionary model of international growth rate differentials. What is robust is not any particular sequence of events but the $1/f^{\alpha}$-noise pattern of the time series that will always generate such patterns if one waits long enough. In other words, we argue that, despite the impact of 'random' events such as US leadership over much of the 20th century, we would expect that similar patterns would have arisen had we been able to 'play the tape twice.' In order to stimulate other contributors to the evolutionary debate to take a similar perspective in the future, further work on methodological issues, such as the status of simulation experiments relative to analytical results, or the statistical evaluation of results generated by computer simulations, is obviously required.

Finally, there remains the issue of the relationship between neoclassical theory and evolutionary growth models. We have already seen that evolutionary theorists, whether old or new, tend to benchmark their results against those of neoclassical growth theorists. Following the logic of the above debate on 'chance and necessity', we would argue that the usefulness of comparing the two perspectives is not very high. The possible directions for evolutionary theory we have emphasized imply that the results of evolutionary simulation models would be of a different class than those derived from conventional models. Just as Newtonian mechanics remained useful after the development of the theory of relativity, the sort of evolutionary results we have in mind would definitely have to say something about the circumstances in which neoclassical predictions are useful, but they would also paint a broader picture in which the role of historical contingencies in the process of economic growth on the one hand, and specifically evolutionary invariant features on the other, would be highlighted.

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TOWARD AN EVOLUTIONARY VIEW OF SOCIO-ECONOMIC SYSTEMS

Mika Pantzar*

Evolutionary Theory in the Social Sciences

Over one hundred years evolutionary theory has played an important role in the social sciences (see Ingold, 1986; Laszlo, 1986). Early Karl Marx and the founder of positivistic sociology, Auguste Comte, are among the most influential proponents of Charles Darwin.

It is important to note that it is not only the natural sciences that have offered theoretical ideas to the social sciences. For instance, the German historian Egon Friedel attacked Darwin because Darwin copied liberalistic free-trade arguments from Adam Smith. Obviously, multi-directional cross-fertilizations among sciences are quite usual (see eg. Clark and Juma, 1987: 45-51; Hirschleifer, 1977; Thoben, 1982). Also the social and political atmosphere influences and contextualizes emerging scientific theories. Thus the popularity of, say, the concept of self-organization is partly related to modern ideologies favoring voluntary choice and spontaneity.

In economics and organization theory, our concern here, Thorstein Veblen's, Joseph Schumpeter's and Kenneth Boulding's voluminous work on evolutionary dynamics should be noted. Other important contributions are Alchian (1950), Allen (1986, 1988); Arthur (1988, 1989a, 1989b, 1990), Clark and Juma (1987), Day (1987a, 1987b), Dosi et al.(1988), Hodgshon (1988); Nelson and Winter (1982). However, it seems that it is organizational ecology (eg. Carroll (ed.), 1988; Hannan and Freeman, 1989) that is the most ambitious and unified programme attempting to apply ecological and evolutionary models to the realm of the economy (see Pantzar, 1991).

History Matters - Path-dependent Processes

In mainstream economics, where nonlinear models have become increasingly standard, the term "path-dependence" has been coined to capture irreversible processes of socio-economic systems (see eg. Arthur, 1988, 1989a, 1989b, et al., 1987; David, 1988, 1989). Path-dependence emphasizes the role of historical contingencies, developmental sensitivity to initial conditions, and the temporal sequencing of technologies and organizations.

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The "butterfly properties" inherent to nonlinear models have directed even mainstream economics toward recognizing the essence of temporality, and different kinds of structural configurations, ie. organizations, which in the case of linearity were not focused (Pantzar 1987, 1989b). In economics it is increasingly recognized that even a small variation in parameters and initial conditions may significantly shape the qualitative properties of highly organized systems.

For example, in situations of collective behavior (eg. the stock market), where there exist both responders and nonresponders (eg. imitators and optimizers, or speculators and fundamentalists) prediction of outcomes can be extremely difficult if there are even minor fluctuations in the initial values (Arthur, 1988, 1989a, 1989b; Day, 1987a, 1987b; Granovetter, 1978; Kauffman, 1995; Zeleny, 1985).

In a similar vein in studies of technology it is well known that proper timing is an essential feature of successful innovations. This applies both on micro and macro levels, and to small and large innovations. For instance many inventions, such as Viscose rayon (invention 1872, innovation 1920), the magnetic tape recorder (1898, 1937) and A.M radio (1900, 1918)), became marketable only after long gestation periods (Sahal, 1983). The gestation period, the amount of time required to bring an invention to the market place, seems to depend on how path-breaking the inventions are. The structure of the American economy in the nineteenth century did not yet allow Viscose rayon, for instance, to become marketable.

Contrary to the standard process depictions of mainstream economics, path-dependent processes might result in:

1) Multiple possible equilibria (The outcome is indeterminate, it is not unique and predictable.)

2) Possible inefficiency (In the case of "bad luck" in the early history of some technologically efficient solutions the final outcome might be non-optimal; eg. in video standards VHS vs. BETA)

3) Lock-ins (Once a solution - eg. the gasoline motor - is reached, it is difficult to exit from this solution.

In socio-economic systems nonlinearity arises from complicated (reinforcement) feedback mechanisms[1]. In brief, and necessarily incompletely: Negative feedback mechanisms often have a regulating (homeostatic) role, whereas positive feedback effects are responsible for growth and change (Laszlo, 1984).

Self-reinforcement is one possible term for positive feedback mechanisms. It goes under different labels in economics: "increasing returns; cumulative causation; deviation-amplifying mutual causal processes, virtuous and vicious circles; thresholds

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[1] From the perspective of cybernetics, most of traditional social and political science has restricted itself to the analysis of negative feedback deviation reducing mechanisms, in which governance is positioned at the "center and on top" (Laszlo, 1984, 144). This is reflected also in the classical analysis of organizational maturation: it was negative feedback mechanisms that were assumed to play a crucial role in organizational evolution (Pantzar and Csanyi, 1990).

effects; and non-convexity" (Arthur, 1988, 10). Self-reinforcement results from feedback effects, such as learning by doing or social systems of mutual interdependencies (see Pantzar, 1989b).

The research potential provided by the path-dependence models dealing with irreversible and possibly unpredictable processes is appealing for historical studies (see David, 1988, 1989). Today this area of research seems to be one of the most progressive fields of research on organization and technology (see eg. Andersson, Arrow and Pines, 1988; Clark and Juma, 1987; Dosi et al., 1988; Leydesdorf and Besselaar, 1994).

Path-dependence, proper timing and the sequential order of possible innovations is very much in the focus of evolutionary studies.

Certainly the debate about the path-dependent economic systems paves the way for more detailed attention to the role of timing (eg. in bringing inventions into markets, or in launching new organizational structures), sequential order of innovations, technological complementarities and self-enforcing mechanisms. This is the very essence of evolutionary theories.

Evolutionary or ecological theories of economics have only partially adopted concepts of recent evolutionary theory. For instance, Nelson and Winter's (1982), and Alchian's (1950) approaches, or the perspective of organizational ecology, concentrate to a great extent on selective forces and homeostatic feedback mechanisms. In crude terms, Schumpeterian market competition is seen to be analogous to biological competition: firms (or daily routines of firms) must pass a survival test imposed by the market (eg. Shuonoya and Perlman, 1994.)

An evolutionary perpective could be seen, however, to imply more than merely the existence of selective forces tending to convergence. More emphasis in evolutionary economics should be given to divergent variation-generation and processes of self-organization, as manifested in the emergence of organizational levels and novel combinations.

Socio-economic Organizing Processes in an Evolutionary Perspective

According to Maynard Smith (1969, 96) biological evolution theory deals with populations of organisms which have the properties of multiplication, heredity, and variation. He also states that any population of any entities with these properties will evolve by natural selection so as to become better adapted to its environment. Given time, any degree of adaptive complexity can be generated by natural selection.

By socio-economic evolution I refer to the interaction of processes which generate variations (eg. inventions and innovations), transmit variations through time and space (eg. learning and imitation) and restrict variations (eg. selection as a result of competition and cooperation). The culmination of this interaction is an increasingly differentiated division of economic labor and an ever higher degree of integration.

Herbert Spencer's definition of evolution is still illuminating: "Evolution is definable as a change from an incoherent homogeneity to a coherent heterogeneity, accompanying the dissipation of motion and integration of matter" (Spencer, 1862).

As seen from the viewpoint of Adam Smith and political economics the evolutionary perspective is classic: to describe the occurrence of change in the coordination and organizational structure of the economic system and enterprises. It is a way to describe the development of the division of labor. My selected avenue of approach is, however, new: a modern general evolutionary theory, which, compared to the former (Darwinian) view, seems to put greater emphasis on qualitative change, the discontinuity and unpredictability of development, and the capacity of organizations to be self-regulating and self-modifying(see Csanyi 1989; Eldredge and Gould, 1972; Jantsch, 1980; Laszlo 1987; Nicolis and Prigogine, 1977).

Evolutionary theory can be thought of as being applicable to a historical study of organizational structure, as the economy moves from an undifferentiated state towards an organized one. Nineteenth century America serves as an useful demonstration of an evolutionary argument. A more thorough overview of this historical period is given in Pantzar (1991). The deepening division of labor and integration into increasingly large units - trusts, corporations, industries - may be seen as a manifestation of the evolutionary process. In other terms, economic evolution manifests itself in the tendency toward more complex patterns of integrated (co-ordinated) activities, and the emergence of novel organizational levels.

The evolutionary perspective of socio-economic systems directs attention to the following kinds of questions:

- How do economic systems of interdepence evolve?
- What, if anything, is the source of form, order and structure in modern large-scale economies (network of economic operations, corporations and industries) viewed as organizations?
- To what extent are historically evolved hierarchic configurations within firms (their organizational structure), and between firms and industries, analogous with hierarchies in nature?

The theoretical perspective developed in my dissertation (Pantzar, 1991) focused on the life of self-modifying systems of interdependence: How do single ideas, independent human beings and economic activities form higher level integrations, and how do different integrations start capturing a role of selective forces?

The relationship between productive operations and the larger entities, i.e. systems, that they comprise is a reference point of the modern evolutionary view in which the traditional static system-environment antithesis of system theory will be replaced by a component-system dichotomy: the components themselves produce the "environment" that restricts their own activity.

In other words, instead of in-depth analysis of different (subjective, technical, etc.) environments we have concentrated on the dynamics of environments: the ways economic actors by their behavior create environments that constrain and enable the actors' further behavior.

An evolutionary perspective does not give a complete answer to these questions. Needless to say, there exist opposing forces which hinder pure manifestation of any pure evolutionary tendencies. Rather, evolution theory seems to propose frameworks based on evolution as a fruitful metaphor for studying economic organizing processes[2].

Certainly, there exist plenty of reference points, different kinds of evolutionary approaches, for the theory of the socio-economic organizing process. There is no single theory of biological evolution. The evolutionary perspective in this article could be connected to the recent developments in general systems theory, more specifically in general evolution theory. The term general evolution research is used as a shorthand expression for the new perceptions of reality and for the new concepts and approaches resulting from research into the behavior of evolving complex systems (eg. Kauffman, 1995).

General Evolution Theory

General evolution theory is concerned with the behavior, maintenance, and self-transformation of complex emergent systems of interacting connected components. It generalizes principles of biological evolution to the realms of the social and physical. Broadly, general evolution theory focuses on accounting for increased complexity. Recent theoretical developments in general evolutionary theory are related to the disappearance of the strict borderline between physics and biology, and a better understanding of nonlinear dynamics.

It should be noted that the concern over nonlinearity does not mean that all the systems are subject to chaotic behavior. Nature as well as society contains regulative mechanisms (of a higher level) that restrict the consequences of microlevel chaotic behavior on the macrolevel. When social systems are approached as consisting of emergent levels of activities, special concern is devoted also to these regulative mechanisms.

The recent insights related to complexity and evolution could be connected to names like Warren Weaver, Herbert Simon, Niles Eldredge, Eric Jantch, Ervin Laszlo, Ilya Prigogine and Vilmos Csanyi. World Futures - the Journal of General Evolution - and the emergence of the Group for General Evolution Research exemplifies quite well the recent (systems) interest in multidisciplinary general evolution research. Biologists,

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[2] One aspect deserves emphasis: usually evolutionary studies concentrate on the actual process of organizing, and not the actual reasons or initial causes. It is roughly the difference between studying how a motor vehicle runs and the way in which it was started up. Evolutionary studies are mainly interested in the process following the initial start-up. The more an economy contains the seeds of its own continuous change, the more relevant evolutionary theory is.

physicists, historians, economists and sociologists are attempting to create a common conceptual framework where concepts like "self-organization, far-away equilibrium, autopoiesis, autogenesis, bifurcation and punctuated equilibrium" are consistently applied to multiple empirical phenomena (eg. Csanyi, 1980, 1987, 1989; Kilmister (ed.), 1986; Laszlo, 1986, 1987; The Science and praxis of complexity, 1985; Yates (ed.), 1987).

During the last decade the concept of self-organization has penetrated also into the terminology of economics (eg. Allen, 1986, 1988; Anderson et al. (eds.), 1988; Ayres, 1988; Clark and Juma, 1987; Dosi et al., 1988; Marris and Mueller, 1980; Proops, 1983; Silverberg et al., 1988). In economics, intuitive strength provided by the concept of self-organization has been increasingly appreciated:

"Clearly, a market economy is not a simple problem-solving machine. It is what cyberneticists have called a Self-Organizing System, a system that can and does modify its own structure and programming in the course of, and as a result of its own operations. Economic theory has traditionally ignored self-organizing processes and has traditionally concentrated attention on the behavior of systems with given structures" (Marris and Mueller, 1980, 33) or "self-organising in the sense that the "order" in the evolution of the system is the largely unintentional outcome of the coupled dynamics between technological progress (innovation, learning, etc.), strictly economic activities (investment, pricing, financing, competition for market shares), and the institutions governing decisions and expectations" (Dosi and Orsenigo, in Dosi et al., 1988: 21).

The specific variant of evolutionary models I have used in my previous study (Pantzar, 1991) of organizational evolution is the replicative model of evolution (Csanyi, 1980, 1987, 1989; Pantzar and Csanyi, 1990). In this model, the organization-environment division is replaced with a component-system dichotomy, in which the most important selective force is the system itself. This crucial, though problematic, distinction makes the replicative model of evolution worth approaching when trying to understand socio-economic organizing processes. The already existing organizations are related to themselves through positive feedback, and the self-organizing properties of the systems are direct consequences of this positive feedback. This process is described as an autogenetic process: "According to the definition of an autogenetic process the components of a system constitute a functional network, which continually renews the same network with an increasing precision, i.e. self-replicates" (Csanyi, 1989, 358).

The Emergence of Autocatalytic Systems of Interdependence

The replicative model of evolution provides us with one potential avenue to approach the organizing processes of, say, the American economy. Very generally, the replicative model illuminates the evolution of "systems of interdependence" (Boudon, 1981), "interlocked behaviors" (Weick, 1969), or in the terminology of general evolution theory the "autocatalytic cycles" (Nicolis and Prigogine, 1977; Csanyi, 1989).

In brief, an autocatalytic feedback cycle is a concatenation of positive influences, where one item in the chain catalyzes another. These causal loops are embedded within larger networks of causalities (see Csanyi, 1989; Weber el al. (eds.), 1988; Zeleny, 1981).

Take an example from the organizing process of the American railroads (for more details, see Pantzar, 1991; Chandler 1977). In the American economy the loosely interconnected railroad system of the 1860s contained many different kinds of separate subsystems, local networks, which were all replicative units. When these subsystems expanded, interrelationships developed among them and total replication became coordinated. Different replicating subsystems became more tightly connected in webs of mutual exchange, cooperation and competition, and finally the components, subsystems, formed a unified replicative system, a national network with unified principles, such as uniform standard time (1883) and standard gauge track (1886).

However, as time went on, the national network compartmentalized into a few self-sustaining railroad systems. This was not the end of the story. The emergence of private motor vehicles started to challenge the bureaucratic railroad firms. Transportation facilities provided by private cars put into question the place of railroad operations as a component in the system of the national economy. Possibly the 1990s will witness a new breakthrough by the railroads, when congestion on the roads and pollution start downgrading the total system's viability.

Thus, in the railroad business, the integration process manifested itself in the tendency for all components to participate in the overall replication, the renewal of the whole transportation system. As a result of this process, a technologically united transportation network all over the continent was a fact by the end of the century.

The emergence of self-sustaining (bank-sphere) interest groups in the US railroads at the end of the century might exemplify compartmentalization as seen from the perspective of the overall system. In this compartmentalization process, certain sets of components, eg. financial groups, separated from others through their co-replication.

The possibility of a system's simultaneous functional differentiation and integration is dependent on the certainty that all sub-systems replicate and coordinate properly. In the terminology of the replicative model: the evolution of systems of interdependence demands high fidelity of component replication. Systems, or components already replicating with relatively high fidelity, can develop functional relationships to each other and then, on a new level, a new system comes into being.

For instance, in nineteenth century America the institutionalization of the labor force and adoption of regular schedules in transportation services were among the critical factors promoting component predictability in the transition from entrepreneurial firms to a corporate economy. Obviously, the emergence of complicated systems of interdependency, such as giant business firms, required a certain "predictability" in component behavior and "clarity in the rules" of component interaction patterns Such constancy was based on good replication[3]

[3] Actually, with the emergence of unifying principles (eg. standards, schedules) and permanent systems of

A Research Proposal: Toward an Evolutionary Theory of Socio-economic Organization

Let me finally anticipate and schematize some general theoretical perspectives on socio-economic organizing processes in order to more fully develop our evolutionary metaphor. I am, by no means, alone in the formulation or proposal of a new evolutionary research programme (cf. Clark, Juma, 1987; Dosi et al., 1988; Hodgshon, 1988, Langlois, 1986).

From the evolutionary perspective a socio-economic organization, say a firm, could be seen as an entity which reproduces itself in a continuous energy and information exchange with its co-actors and environment. An economic organization should belong to an autocatalytic system of positive loops in order to expand or exist. In other words, if firm A increases the probability of genesis and maintainance of firm B, and firm B does the same to firm A, then in this autocatalytic cycle the two firms mutually enhance each other's rates of replication and gain an advantage over other firms. It is not only firms that are selected but also operations and networks of operations by even higher level networks. Instead of firms we might talk about, say, industries, or routines that are reproduced (and selected) through participation into different cycles. According to this view, organizations are processes within processes rather than given stable entities.

For intance, the question could be posed as to whether giant modern firms are different "species" from traditional small firms. If they are, they could be identified as two different kinds of autocatalytic cycles with different spatial and temporal reach. In the case of an integrated corporation the business organization participates in many replicative cycles and its components form multiple interconnected cycles, whereas in the case of a small firm it participates perhaps in only a few cycles, and it consists of simple interaction patterns of constituent components. Furthermore, the management of giant enterprises seem to rely on more general, higher level principles- inherent to "cycles of cycles". This is manifested in the larger temporal and spatial reach of management control and more general managerial epistemologies. Especially, in the case of giant business within multiple autocatalytic cycles we should perhaps discard the standard notion that assumes a clearcut separation of the "inside and outside" of a firm.

The evolutionary view as adopted in this article studies economic organizations as consisting of subsystems and the ways these subsystems are related to each other; the

interdependency it is quite immaterial whether we are talking about the emergence of conflictual or cooperative networks. Emerging integrating principles follows from some sort of sequentiality of interaction, reciprocity and repetition (see eg. Gambetta, 1988). Game-theoretical analysis of the emergence of norms and institutions well exemplifies this point of view (Axelrod 1984; Ulmann-Margalit (1978)): eg. games of coordination, games of the prisoner's dilemma type, games of inequality preservation. The fact that in evolving systems of interdependency the integration and conflict view are not necessarily exclusive is nicely illustrated in Georg Simmel's "Der Streit" (1908, see Simmel (1970)): Even war situations rest on rules governing interaction patterns. Axelrod's book on the evolution of cooperation (1984) exemplifies the power of shared principles and reciprocity in war: French and German soldiers in the battles of the First World War started knowing in advance where cannon shots were directed and thus avoided the possibility of being killed. In a stabilized war situation it paid to be predictable.

ways networks of business interactions generate macrostructures and macrostructures select elements of those networks. Thus, firms or industries are each other's environments; there does not exist any oneway relationship between the environment and the system. In co-evolutionary terms, evolution is characterized by continuous reciprocal responses of two closely interacting species. In accordance, business organizations as active agents construct their own objective environment when deciding whether or not to participate in feedback cycles.

Consequently, there is no clear-cut separation between cause and effect any more. There is a continuous process in which an organization (organizational level) evolves to solve an instantaneous problem that was possibly created by the organization itself. When organizations construct, intentionally or non-intentionally, an environment they generate the conditions of their own survival and replication. In other words the environment is both the object of selection and the creator of the conditions of that selection.

In this kind of conceptualized "world", an organization's creativity, as well as its managerial skills, might be manifested in many ways. In emerging cycles of interactions novel hidden properties of components might be revealed. Creativity might arise from an organization's ability to recombine its components in novel ways. Perhaps an organization's creativity might also arise from its capacity to affect the conditions of its own selection. Our perspective emphasizes the diversity of managerial tasks, as well as the occasionally impossibility of managing evolving systems. The need to recognize and simultaneously anticipate feedback cycles of different temporal and spatial horizons, means that the position of a top manager in a giant company is a demanding, if at all possible, task.

What could a firm's optimization problem be when no clear limits between system and environment exist? Possibly instead of solving problems within a given context, firms might decide what are the proper temporal or spatial dimensions of cycles in which they participate; acknowledging the highly uncertain consequences of participating in a cycle. Possibly, the fittest firms are the ones that best enhance the autocatalytic behavior of the reward loops in which they participate. Perhaps, the best strategy is to support your neighbor by not adapting too fast, ie. by not changing the environment of your symbiotic relationship. It might be that long-term persistence favours generalists with bureaucratic structures rather than fast adapting specialists. The best strategy might be one that allows persistence by maintaining flexibility.

Tentatively, it is possible that the process of evolution does not involve short-term maximization of efficiency in terms of profits or sales at all, but instead the development of adaptations that contribute to long-term persistence. In this game the pay-off is to stay in the game.

Adaptations are never perfect. Total adaptation is impossible in an ever changing environment. In a stable environment adaptation would mean absence of freedom and errors, ie. any kind of progress. Total nonadaptation would mean unrelatedness of organizations in horizontal terms and unrelatedness of organizational levels in vertical terms. Especially the latter form of unrelatedness of parts and totality is absurd. It is hard to imagine any system without connections to its components

When the existence of an organization is correlated to the success of the autocatalytic loop feedback cycle it participates in, any practices of an organization that are useful from the point of view of totality will be rewarded in the next pass - and vice versa. It is possible that all the original members of the loop are replaced in turn, while the loop itself persists beyond the more transitory durations of its components. The same feedback cycle might play an active role in influencing what the replacement parts should be. Stability of managerial capitalism or big business might be unrelated to the identity of the players.

The fact that today formal control hierarchies seem to be losing their basis even in big firms and nation states is a useful reminder of the fact that human beings have expanding tools and skills which might oppose the forces of increasing specialization and domination from above. On the other hand, huge problems, such as an unbalanced relationship between the North and South, between Man and Nature, cast doubts on the overall progressiviness of cultural evolution.

It might very well be true that all the other factors of socio-cultural evolution are replacable, except human beings with transformative abilities. In the ordinary routine with human beings as components there is no need for a creative agency. The less routine there is in the way organizations under consideration work, the more emphasis is there on entrepreneurial functions. By entrepreneurs we here refer to any human beings or group of human beings with the ability to act and think "differently", ie. to combine existing resources in a novel way.

We can reasonably assume that it is human beings that go beyond the limits of mere passive components in social evolution. It may well be entrepreneurs that resist forces of disciplination, routinization and rationalization. As tasks and problems become routine, entrepreneurs take another step toward a higher evolutionary level with less replicative quality and more freedom. However, this does not necessarily mean progress, it may only mean continuous change: Solutions to problems generate new problems.

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EVOLVING ECONOMICS OF TECHNOLOGY POLICY: Evolutionary Framework and Economic Foundations

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Introduction

The economic, social and ecological problems we face currently - globalized techno-economic competition, unemployment, ecological damages, de-materialization of production - have at least the following common characteristics: They relate to technological change and they are complex in nature. As several economists from different backgrounds argue, the problem-solving of these issues calls for an economic and multidisciplinary analysis which not only deepens our understanding of these phenomena and their relation to technological change but also produces normative guidance to problem - solving in technology policy and related policy fields. The specific *economics of technology policy*, capable of dealing with these problems, is, however, still in its infancy.

The current economic analysis of technological change and related technology policy is based on two different approaches: standard economics and evolutionary economics. These approaches are based on a different mode of thinking, but there is not, as Dosi stresses, any sharp discontinuity between them but rather a fuzzy continuum (1991, 5). Schumpeter recognized the public and private aspects of technology but his explicit policy analysis was fairly scant. Seminal contributions in the development of specific economic analysis of technology policy were Nelson 1959 and Arrow 1962. Since then, several contributions in standard economics as well as in institutional and evolutionary economics have been published (cf. Stoneman 1987).

The economists from Neo-Schumpeterian, evolutionary, institutional and other backgrounds have produced several studies analysing the role of technology policy in different countries (for example, Freeman 1987, Nelson 1993 ed, Vuori and Vuorinen eds 1994). Nevertheless, only a limited number of studies have been carried out in order to develop an explicit economic analysis and analytical framework for the purpose of analysing technology policy. Some of the early contributions were Rothwell and Zegveld 1981, Nelson and Winter 1982 (chapter VI), Justman and Teubal 1986. Justman and Teubal produced a conceptual technology policy framework that is based on market failure and that synthesizes a neoclassical approach with the normative economics and Schumpeterian view of innovation. Their model consists of the infrastructure for innovation and support for specific R&D projects. Stoneman 1987 is an ambitious attempt to compile the main elements of the economic theory of technology policy into one book. Tassey, in turn, elaborated the framework

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that he calls the infrastructure model for innovation policies (1990, 1992). The prominent contributions within the evolutionary economics of technological change are, in addition to Nelson and Winter 1982, also several papers of Nelson (1987, 1990 a), Metcalfe (1993, 1995), and Mowery.

Several of the above-mentioned scholars, especially those working in the context of evolutionary economics, accentuate that the standard economic approach, due to the limitations of its basic axioms, framework and methodological principles, does not offer a sufficient analytical context and tools for analysing the profound economic problems related to technology policy. As Metcalfe formulates, *ill-defined questions cannot reach well-defined solutions*[1]. Against this background, this paper discusses both the problems of the standard approach and especially some of the complementary and alternative opportunities that the evolutionary economic approach offers to the economic analysis of technology policy.

What are the characteristics of *evolutionary economics*, refered several times in this article. In this book Kuusi and Loikkanen discuss some general characteristics of evolutionary approach, and papers of Verspagen, Lundvall and Pantzar relate to this issue from different perspectives as well. Subsequently, with respect to the evolutionary economic approach, this article refers to the above-mentioned contributions and, against that background, focuses on an evolutionary view to the economics of technology policy. As discussed by Kuusi and Loikkanen, evolutionary economics is still a diverse and evolving research area. Likewise the evolutionary economics of technology policy has been a coherent body of ideas only for the past two decades or so, and the integrative analysis is still far from complete (cf., for example, Metcalfe 1995, 410). This fact provides further motivation to examine potential contributions that the evolutionary approach may make to the economics of technology policy.

Definition of Technology Policy and the Need for a Normative Analysis

Technology policy relates to the process of technological change, how it works and how it can be improved and streamlined by governmental measures. Policy seeks to influence especially decisions of firms but also those of other actors and institutions that affect the innovation process. Thus technology policy is often called innovation policy. Technology policy may be defined as a set of policies involving government intervention in the economy with the *intention* of affecting the process of technological innovation (Stoneman 1987, 4-5). The definite goal normally given to technology policy in policy documents is to contribute to the welfare of society (see, for example, Towards...). Innovation is assessed to be crucial to industrial efficiency and competitiveness, to economic growth and ultimately, to the benefit of society at large at least in the long-term (Rothwell and Zegveld 1982). The standard economic analysis emphasizes this target in the context of optimizing and maximizing the

[1] Metcalfe made this notion in a seminar on innovation systems and technology policy in an evolutionary framework in Tannishus, Denmark, January 25-28, 1995.

behaviour of agents. For example, according to Stoneman the objective of technology policy ought to be to maximize or increase welfare (1987, 4-5). In the evolutionary approach, static optimal welfare is not taken as a point of departure because of the lack of an absolute objective welfare standard by which economic change can be evaluated (e.g. Metcalfe 1995, 414).

The evolutionary analysis concentrates on the process by which a public interest becomes defined (Nelson and Winter 1982, 380)[2]. The public interest relates, in turn, to the definition of welfare in economics. One consequent problem related to welfare in the context of technology policy is how much weight to put on the promotion of industrial competitiveness in order to create economic conditions for welfare, compared to the weight that will be put on broader welfare targets, for example, social and ecological issues. Seppälä and the author have assessed the development of Finnish technology policy from this perspective elsewhere (Loikkanen and Seppälä, see also other articles in Aichholzer and Schienstock), and only some remarks on this point will be made in this article.

The evolutionary analysts emphasize that the economic theory ought to be normative in nature. What does that mean in the context of technology policy? According to Nelson and Winter the principal criterion by which a theory ought to be judged is its ability to illuminate policy issues. Consequently, "it is incumbent upon us to indicate at least roughly how our evolutionary theory frames certain policy questions" (1982, 385)[3]. Freeman also stresses the certain compatibility of theory and empirical phenomena: A satisfactory theory ought be the one which conforms more closely to the available empirical evidence (1988, 4). Saviotti and Metcalfe emphasize the importance of the normative perspective to the theory formulation (1991, 22): The compatibility of conceptual apparatus and empirical analysis enables economic theories to be applied to particular situations, and thus empirical analysis can serve as a basis from which to infer further theories[4]. Thus the empirical perspective determines the setting of analytical questions. In the evolutionary framework the agenda for policy research of innovation will be shaped rather by policy questions than economic theory (Metcalfe 1995, 409)[5].

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2 "We think it useful to view the role of analysis in public decision making as a part of the process by which a public interest gets defined. By that we do not mean that studies *identify* a true public interest in any strict objective sense. We mean that studies help to *define* the public interest." (1982, 380). Nelson and Winter devote a lot of space to discussing the role of economic analysis in policy making (see 1982, 379 - 395).

3 "..our qualitative examination of the problems of normative economic analysis, albeit a preliminary one, makes it clear that an evolutionary perspective can provide insights into what the economic system "ought" to be doing" (Nelson and Winter 1982, 402).

4 Stolper sees theory and policy as mirror images to each other, "with the theorist assuming as given what the policy maker wishes to change and vice versa" (Stolper 1991, 190).

5 About detailed evolutionary epistemological perspectives, see e.g. Clark and Juma 1987, Ch. 1 and 75-79.

Framework of Evolutionary Technology Policy Analysis

We may start from the problem which the technology policy analyst (or policy-maker as well) faces in the planning, analysis or evaluation of policy, ex ante or ex post. Of central importance is her/his ability to perceive the whole scope of policy, its different components, and relations and causalities between the components. Consequently, a comprehensive analytical framework which consists of the core constituent components of policy may be of support in the assessment of the expected or occurred impacts of policy, in the understanding of causalities between policy elements, and in focusing the intervention areas and respective measures. The main components of the evolutionary framework of technology policy are outlined in Figure 1.

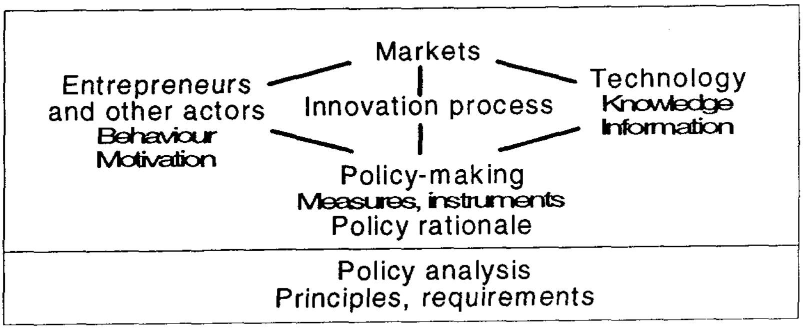

Figure 1. The framework and main components of technology policy analysis

The focus of technology policy analysis is the dynamic innovation process. The main actors of the innovation process are firms with their innovation activities. Other relevant institutions are, for example, public R&D centers, universities, banks financing innovation activities as well as the authorities in charge of the promotion of technology transfer and the coordination of technology policy. The behavioural rules are of special importance in the evolutionary context and one of the key components of policy analysis. Essential ingredients of technological change are the levels of technology, to use Metcalfe´s taxonomy, the knowledge, artifacts and skills. Technology policy-making, with related policy measures and instruments, is aimed at influencing the innovation process. Policy analysis links together the game of all these actors, factors and institutions, and government intervention is based on a more or less conscious or recognized economic rationale[6]. The components are numerous and their interrelations complex and dynamically changing.

The present paper considers these components in the evolutionary economic context. However, all the components of the framework are not discussed; instead, the paper concentrates only on two issues. (Other components, such as the innovation process

[6] The sophisticated policy analysis is based on best available data, indicators and respective input/output schemes. These are not added as a component to the framework but are taken here as a truism.

and systems of technology, are considered in other articles of this volume, e.g. in Lundvall, Verspagen, Kuusi, Pantzar). The present article first discusses the economic foundations of technology policy. This issue is first considered briefly from the perspective of standard economics, and then reconsidered from the perspective of the evolutionary approach. Another topic discussed briefly is the behavioural realm of the evolutionary approach and its consequences for technology policy analysis.

Reconsideration of the Economic Foundations of Technology Policy

The economic foundations (or *economic rationale*) for intervention in industrial innovation have been discussed in economics especially since Nelson (1959) and Arrow (1962). This chapter discusses this issue with some concluding observations from the perspective of the evolutionary approach.

As discussed earlier in this article, the definite target of technology policy (according to any economic approach) is to contribute to social welfare. Traditional welfare economics assumes the existence of a socially optimal level of R&D that becomes defined according to the marginal utility principle of maximizing the behaviour of economic agents. Welfare is conventionally measured as a surplus to consumers, producers and government (see Stoneman 1987, 81; Grossman 1990, 89-93). A socially optimal level of R&D is defined as the volume of R&D at which the social benefit of marginally reducing the expected completion time equals the marginal social cost (e.g. Kamien and Schwartz 1982, 187; Dasgupta 1987). The analysis of intervention in innovation and R&D in the standard framework concentrates on the question of whether the private sector tends to invest ´too little´ or ´too much´ in R&D compared to the level of R&D which is optimal or desirable in social terms. These points of departure relate also to "the new growth theories"[7]. In this chapter hypotheses of under- and over- allocation of R&D are presented only in a simplified form, with the aim of picking up only the essential features of the hypotheses. The economic literature in the field is, nevertheless, broad and diverse (see e.g. Kamien and Schwartz; Stoneman 1987; Beath, Katsoulacos and Ulph 1995). In the following the main ideas of these two hypotheses will first be briefly discussed. Then these hypotheses will be assessed from the evolutionary angle.

The hypothesis of the existence of social under-allocation of R&D is based on assumed exceptional characteristics of *knowledge good*, the indivisibility of knowledge, problems in the appropriability of knowledge, its durability compared to normal goods, and low costs of transfer of knowledge (Arrow 1962). Due to these characteristics the knowledge good has external economic effects which make investment in R&D exceptionally risky. If the innovating company manages to create

[7] "The new growth theories" differ from standard models by treating technological change as an endogenous and not an exogeneous variable. The framework and assumptions of these theories, related, for example, to behavioural rules of agents are familiar from the standard approach. In this paper only few remarks are made on new growth theories. In case of additional interest, see, *inter alia* several papers of Grossman, Helpman, Romer and Lucas, as well as Saarenheimo 1994. From the evolutionary critical perspective, surveys of Verspagen 1992 and Nelson 1995 are of interest.

new knowledge, a part of it may leak as external effects for the benefit of competitors and the original creator may reap only a part of the returns. Thus the private incentive to engage in R&D may be too small and non-market institutions are needed to correct market failure by trying to guarantee that at least the lion's share of R&D returns ís reaped by the original discoverer. One appropriate instrument is patenting. The aim of a patent is to grant a temporary monopoly right to the discoverer for the exploitation of R&D returns and thereby to guarantee the lion's share of emerging R&D returns to him/her. Also R&D subsidy (or respective tax relief) may be used as a policy instrument with the aim of encouraging firms´ innovative activities and thereby closing the gap between actual and socially optimal R&D. Governmental incentives may be financed by lump-sum taxes which are justified by emerging benefits for the whole society[8]. On the same economic grounds government may establish and maintain public R&D laboratories as policy measures[9]. Such a solution transfers the risky production of new knowledge partially from the private sector to the public sector and may reduce the threshold of firms to perform R&D. All of these instruments are common in most industrial countries and they may close the gap between actual private R&D investments and the socially desirable level.

Another reason for intervention in industrial innovation, presented in the economic literature, is "opposite" to the first one. Dasgupta and Stiglitz argue (1980) that, due to competition, the market economy is tending rather to over-invest in R&D than to under-invest, as compared to the socially optimal level. The original under-investment hypothesis of Arrow is based on the assumption that only one firm is engaged in R&D activity, which is protected by barriers to entry in research activity. In addition, the model assumes a closed economy[10]. Arrow's model thereby eschews an essential element of R&D competition (Dasgupta and Stiglitz 1980, 2). When R&D competition is introduced, the level of industrial R&D may exceed the socially optimal level[11]. Consequently, duplicative R&D efforts may emerge in some areas, and, in order to avoid dissipation in social terms, a social planner becomes necessary in order to coordinate and reconcile R&D investments.

The previous simplified analysis could be elaborated further, for example, by introducing technology diffusion into the model, as done by Stoneman (1987, 84-97). For the present purpose the previous description is, however, adequate. The two hypotheses, based especially on externalities of knowledge good, are as such logical

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8 Due to banks´ inadequate scientific expertise in R&D problems, Kanniainen interestingly proposes subsidies for monitoring the activities of lenders (1992, 54-55).

9 The economic foundations for intervention in the case of a public R&D institute are discussed in Loikkanen 1995.

10 Arrow in his seminal paper well recognized the problems of standard economics in the analysis of information: "...*information* is a commodity with peculiar attributes, particularly embarrassing for the achievement of optimal allocation." (149, 1962).

11 "There is some presumption of excessive duplication of R&D activity in a market economy in the sense that while each firm undertakes less than the socially optimal level of R&D activity, market equilibrium sustains an unwarranted number of firms, so that industry-wide R&D expenditure is excessive" (Dasgupta and Stiglitz 1980, 3).

explanations for governmental intervention in industrial innovation. Current policy instruments of advanced countries may be reduced to these arguments, and references to them are made in several policy documents[12]. In the literature of evolutionary economics these hypotheses are criticized due to assumptions of standard welfare economics (perfect information, optimality, homogeneity of actors, and so on; see Stoneman 1987, 17-25), due to the used knowledge concept and to some other problems which will be discussed below. As several observers argue, a number of assumptions made in these hypotheses are controversial from the perspective of actual techno-economic developments, and are thereby rejected in the evolutionary approach.

One problem of the described market failure analysis in the context of technology policy is that market failure is analyzed as an *ubiquitous* phenomenon. Its dependence on specific situations and on different economic and social environments is not specified. Such specific situations may relate, for instance, to differences of countries, industrial branches, types of technologies, types of research, and so on[13]. Consequently, it is difficult if not impossible to assess whether imperfect markets produce more comparative advantage, for instance, to some countries than to the others, or to some industries than to the others. The nature and developments of technologies in different industries do vary essentially, as do the role of and reasons for governmental intervention (Nelson and Winter 1982; Nelson and Soete 1988). While saying this, the question naturally arises whether the ubiquitous nature of market failure is an obstacle to analysis of its role. Can market failure be analyzed in circumstances of specific situations mentioned below? The problem returns to the difficult task of defining the socially optimal level of R&D. It is a problematic issue both on a aggregate level and on a specific case level.

In the economic literature the socially optimal level of R&D as well as hypotheses of under- or over-investment in R&D are discussed mostly on a highly theoretical level. No successful empirical determination of these levels, based on actual empirical data, has been made[14]. Intuitively the hypothesis of under-allocation to industrial R&D seems be more relevant than the over-allocation when compared to the socially optimal or rather socially *necessary* level of R&D[15]. From an empirical perspective this proposition may be defended, for example, by the relatively low percentage of companies involved in R&D activities when compared to the total number of companies. In Finland, for example, according Statistics Finland some 1500

[12] "Public support for product development is also justified by the great externalities which industrial R&D has in the productivity of the national economy, the growth of the national knowledge-base and the development of the innovation system" (Towards..., 41).

[13] The framework of the analysis of Dasgupta and Stiglitz is from standard economics and, as Beath, Katsoulacos and Ulph (1995, 134) remark, if product differentiation and product specific research paths are introduced to the model, the claim of needless duplication of research loses its force.

[14] In the empirical analysis of R&D both private and social returns from research have been assessed, but in this type of analysis the problem setting and empirically oriented framework differs from theoretical market failure analysis (see e.g. the survey of Mairesse, J. and Sassenou; Vuori).

[15] This also is the prevailing general conclusion of studies of "the new growth theory" (e.g. Romer 1990, Grossman 1990). The difference between optimal and equilibrium growth rates depends on the scale of innovation and monopoly power. See also the survey of Verspagen 1992, 23-35.

companies performed R&D in 1993, and in 1994 less than 500 Finnish companies applied from domestic patents (Tiede ja Teknologia 1995). The percentage of companies performing innovation activities and exploiting the fruits of science could be much higher, and raising this percentage is an important task of technology policy. In this context, arguments have been presented that the share of basic research is not on the socially optimal or desirable level. Nelson referred to this in his seminal paper of 1959: Although one cannot make an airtight statement based on welfare economics, "we are not spending as much on basic scientific research as we should. But I believe that the evidence certainly points in that direction" (1959, 161).

Some loose notions on the existence of social under-investment in R&D have been made in the literature. For example, Fransman draws a conclusion in his study on IT in Japan that obvious under-investment in R&D emerges without governmental action. There is a need to invest especially into the creation of technologies for the *day after tomorrow,* where the degree of commercial uncertainty is great. Firms, due to bounded visions, do not invest in these technologies in socially desirable amounts, and the markets may not generate a sufficient amount of research cooperation either (1990, 3)[16]. Polt also makes an effort to link the theory of market failure to empirical perspectives in his evaluation of public R&D programs (1992).

The assumption of external effects of new knowledge, emerged from R&D, is a relevant axiom in any economic analysis. However, the knowledge concept used in several standard economic studies is a problematic one. Knowledge is namely assumed to be easily and cheaply or sometimes even freely codifiable, reproducible and transferable. Such a ´free good´ nature of knowledge is, however, true only in some exceptional cases of widely applicable generic technologies. Certain generic technologies may have, as Nelson proposes, "latent" public good properties, latent meaning "zero real incremental costs to extending use to more parties" (1987, 76; 1990 b, 35). Nevertheless, in the case of specific technologies, the problem of transferring knowledge, for example, from one company to another, is a complicated process in which learning plays an important role. The problems of technology transfer are due to the nature of technological knowledge that is tacit and specific in nature and, consequently, rather more private than a public good (Dosi 1988, 222-224).

One problem of standard market failure analysis in the case of innovation relates to the omission of the innate nature of technological change. According to the under-investment hypothesis markets fail to invest sufficiently especially in research of *the technologies of the day after tomorrow*. In the determination of future investments in R&D and their future returns, risks relate especially to uncertainties in the prediction of market demand in the future. The uncertainties are due to the unpredictable behaviour of firms and other economic agents. Firms are not able to trade risks in an optimal fashion in future markets. The reason is that these markets do

[16] Due to firms' bounded visions, complementary and compensating roles may be played by other organizations like government research institutes and universities. In the Japanese system the government and other procurers such as the NTT have played roles in economizing on transaction costs and increasing the amount of research cooperation.

not exist in any sense sufficiently for individuals to trade risks in an optimal fashion (Metcalfe 1993, 2). Thus the question is not of failing markets only as discussed in the standard approach but of *unknown* or totally *missing* markets. The reason for the inability to trade risks in future markets is in the nature of the innovation process. This process is not only influenced by uncertainties but itself also *generates uncertainties*. Thus innovations relate to information asymmetries between the present and the future (Metcalfe 1993; Dosi 1988). These asymmetries are necessary conditions for the technical change to occur in a market economy and consequently may not be called market failures. "Thereby the asymmetries of innovation and information are inseparable and thus innovation and Pareto optimality is fundamentally incompatible" (Metcalfe 1993, 2).

In the previous paragraphs some of the notable shortcomings of market failure analysis of standard economics are examined. Some additional critical remarks may be made. The standard analysis often concentrates merely on industrial R&D. Nevertheless, besides R&D, the successful innovations are an outcome of several processes and investments other than R&D, for example of companies´ marketing efforts, organizational factors, and so on[17]. Concentration on R&D in turn raises the problem of inputs and outputs in innovation. R&D investment is an input in the innovation process. However, often only R&D expenditures are treated as a proxy of knowledge capital (see, for example, Coe and Helpman 1993). A serious if not even paradoxical problem in Arrow´s original model was the assumption of a closed economy. Today the stimulus for technology policy comes from what is perceived at best practice in a world system of international competition, where technological leads and lags are of central importance (e.g. Pavitt 1993, 35). During the globalized techno-economic development the innovation systems are country specific and may be in some countries more flexible, adaptable and adjustable to innovations than in the others. The capability and related speed in the exploitation of basic research between countries may differ greatly. The critical remarks can be extended also to empirical policy analysis which is made in the framework of the standard approach. Such studies are often based on economic data of macro or branch levels. Such an analysis may miss essential information of the "micro realm" in explaining, for example, the productivity paradox. In the literature some evolutionary influenced contributions have tried come to grips with this problem by trying to link micro and macro levels to each other (see, for example, Carlsson, 1990).

In sum, the standard economic analysis of market failure gives several interesting and relevant insights into fundamental economic issues of governmental intervention in technological change. For example, the issues raised in the analysis of the interface of public and private aspects of technology open up a useful and important view to essential topics. The problems of this analysis are, nevertheless, obvious and indisputable especially from the perspective of evolutionary economics. In Dosi´s words, there is not any sharp discontinuity between the standard approach and the

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[17] Costs by stage of innovation development may vary greatly, depending on the technological area and other variables. For example, in the ERIP programme in the U.S. at least half of the technological innovation costs are incurred in the post-R&D phases of the development process (Brown 1990).

evolutionary apparoach but rather "some fuzzy continuum" is taking place. It will be interesting to see in the future developments of economics whether and how far "the new growth theories", or perhaps the efforts in the evolutionary approach, will serve as a point of departure for a new paradigm. Nevertheless, the critical remarks presented above to the standard approach are based on the argumentation of the evolutionary approach. Below, in this spirit, a few additional characteristics of the evolutionary approach to the economic foundations of technology policy will be considered.

The point of departure for governmental intervention in the evolutionary context is the unpredictable nature of technological development where the future markets are unknown. When technical change is analyzed as a collective and evolutionary process, some central issues of the traditional approach, such as externalities or (near) duplication of R&D efforts, may become even necessary components of analysis. Duplication of efforts may follow already from fundamental characteristics of evolutionary processes that are inherently wasteful (Silverberg 1990, 181; Nelson 1990 a, 194). The key concept in the innovation process is learning, on the level of individuals, organizations and collectively, through networks of feedback unfolding over time between co-operative and competitive agents. In governmental decision-making, man-made failures become as likely as market failures. Simply the financial imperative to make decisions may give a sufficient ground or "rationale" to technology policy (cf. Foray 1993, 10). From this perspective, *effectiveness* in the use of public R&D investment becomes a significant problem of technology policy.

In the evolutionary realm the interest in technology policy analysis turns from market failures to the enhancement of competitive performance and the promotion of structural change. The role of government becomes primarily a coordinator of the innovation system (Metcalfe 1993, 5; Mowery and Rosenberg 1989). More than subsidizing the creation of knowledge, technology policy involves measures such as the promotion of technology diffusion (Mowery 1995, 517; Maastrich Memorandum). The transfer of tacit knowledge can be promoted by supporting the mobility of scientists and technologists between companies and other relevant institutions (see SPRINT / EIMS). The pervasive influence of technological change in society necessitates the consideration of other than economic factors, i.e. on an analytical level multi-disciplinary considerations and on a practical policy level multi-political considerations. For example, several examples of integration of social and ecological aspects with technology policy exist already (see, for instance, Loikkanen and Seppälä).

The central focus of technological change and that of technology policy in the evolutionary realm is in the introduction of novelties to the system. Thus the tasks of technology policy relate, for example, to the promotion of *routinized behaviour* favouring innovation, *generation of variety* of technologies by *searching*, the development of *selective mechanisms* of the innovation process in the *selection environment*, as well as the streamlining of the interaction of actors participating in the innovation process. The concepts with italics in the preceding sentence are less familiar in standard economics textbooks and they will be discussed more extensively in the next chapter.

Evolutionary Behavioural Realm and Implications for Policy Analysis

The behavioural assumptions of actors participating in the innovation process as well as specific characteristics of factors of innovation play an important role in the evolutionary analysis of technology policy. These assumptions differ remarkably from those in standard economics. Consequently these assumptions, especially the relevant ones from the perspective of policy-making, are worthy of a short overview.

In the innovation driven "Schumpeterian" competition, profit seeking and competitive imitation give motivation to entrepreneurs. The primary institutions in the innovation process are firms, but other institutions, such as universities, R&D laboratories, technology transfer and liaison offices, as well as banks and industrial associations all play their essential roles. A definite behavioural agent is always an individual person. The actors« behaviours vary and the special focus of evolutionary theory is, how firms in different industries come to behave and innovate differently (Metcalfe 1995, 410). Subsequently, varying policy measures are necessary as well.

Due to the limitations of human memory and brain capacity, the behaviour of actors is boundedly rational and myopic. We lack the capacity to sharply separate our knowledge from our (proximate) values (Metcalfe 1995, 382). The values are relevant in policy analysis as well. Likewise the rationality of firms is bounded, as is their ability to envisage the future. Consequently the decision-making is based partly on rules of thumb and heuristics (e.g. Dosi 1988, 224). The behaviour of agents is not optimizing (alike is often assumed in standard analysis) but *satisficing*. It means that firms do not possess well-articulated global objective function because individuals are unable to think through all of their utility tradeoffs, and, in part, because firms are coalitions of decision-makers with different interests that are unlikely to be fully accommodated in an intra-firm social welfare function. Satisficing behaviour holds true for policy-makers, too. Policy-making tends to follow certain behavioural path-dependent trajectories. The changes in policy are evolving from a base that is the outcome of a sequence of earlier changes, which in turn set the stage for future evolutionary developments (Nelson and Winter 1982, 35; 211; 376).

In the evolutionary context, regular and predictable behavioural patterns are called *routines*. The main forms of routinized behaviour are searching, selection, imitation, and adaptation. The economic agents learn from experiences. The learning is bounded and determined largely by previous paths, contexts, cultures or histories. Nelson and Winter separate *existing routines, which* govern the behaviour in the short run, and *augmenting routines,* which determine, for example, the augmentation of firms´ capital stock or modify various aspects of operating characteristics. Habits and routines act as *organizational memory*, resembling and presenting the organizational «genes« of «organizational genetics«. The routines that have proved to be successful, may be transferred from firms to other firms by imitation, buy-out, or mobility of labor. The processes that guide and change routines can be modeled as *search activities,* as Nelson and Winter did (1982, 9; 16-17, 163-192). New routines depend especially on the capacity to learn. With the help of their R&D activities firms are searching for the knowledge of the goods. Firms´ search policy can be characterized as the determination of the probability distribution of what will be found through search, as a function of the number of variables (Nelson and Winter 1982, 18).

The behaviour of actors is due to the changes in markets or other *selection environments.* Adaptation to the selection environment takes place through learning. The economic actors not only adapt to changes in the selective environment but also influence it by participating in the creation of conditions for their survival, maintenance and transformation (Pantzar 1991, 7). Variation in the behaviour of agents is a crucial characteristic because it makes the evolution possible. Variation may be *intentional* or *guided* or *unitentional,* i.e. blind in the sense that it is unpredictable ex ante (Metcalfe and Boden 1992, 49. Innovation normally represents intentional variation that is purposely undertaken in the pursuit of competitive advantage.

The behavioural characteristics of institutions and actors, described only briefly above, have important implications for policy analysis. Policy-makers not only have to take the behaviour of actors into account but also recognize that respective behavioral rules relate to themselves as well. They are part of the same discovery process and subject to the same limitations as the individuals whom they seek to influence (cf. Metcalfe 1993, 18)[18].

The evolutionary approach distinguishes two important objects of technology policy, the influence on *variety generation* and on *selection processes.* The central purpose of the policy becomes the stimulation of innovative capabilities of the economic system, the enhancement of learning capabilities of firms and other institutions, in order to generate the variety in behaviour (Metcalfe 1993, 7; 1995; 449, 453). The policy implications also relate to the promotion of co-makership and coupling of activities of all relevant institutions contributing to innovation activities.

From the policy perspective the issue of *predictability* of technological change is of importance. Boulding argues (1981) that prediction is possible only in systems like celestial mechanics, which have stable parameters. This is not the case usually with techno-economic change, although there are several ways to introduce the risk[19]. As discussed in the previous chapter, the relations between input and output are subject to considerable uncertainties. Thus the unforeseen and unintended consequences of

[18] The premises of rational policy-making are violated by Lindblom's notion (1959) that governmental policy-making is not a neat and orderly controlled process but a messy process of "muddling-through". The policy-maker tries to cope with a world even though he knows that it is too complicated. The theory of "muddling-through" was developed in the 1960s in the United States and may be controversial to apply to current policy-making. Nevertheless, it well accentuates the boundedly rational nature of policy-making.

[19] According to Metcalfe the ways the risk may be introduced are, for example, by making the probability of discovery an increasing function of innovative effort; by applying the theory of order statistics to define the expectation of improved performance as a function of innovative effort; by using Markov theory to define the probabilities with which innovations take place and the probability distributions of innovations (1995, 454).

innovation programs are central in the history of technical progress. Additional uncertainty arises from moral hazard and adverse selection[20]. The evolution leads to a change of parameters and is therefore essentially unpredictable (Saviotti and Metcalfe 1991, 20). Consequently the capability to envisage the future techno-economic development is bounded as well. Nevertheless, the *processes* translating novelty into coherent patterns of change are not unpredictable and, as Metcalfe stresses, it is on this distinction that the role of technology policy hinges (1993, 5). Thus the evolutionary policy-maker is, rather than to impose predetermined outcomes, more concerned to influence the processes related to innovation and to enhance the adaptive learning capabilities of the firms.

As the examples below show, from the evolutionary behavioural context several proposals and recommendations to technology policy analysis are to be drawn. Important aims of policy are, for example, the encouragement and promotion of variety and diversity. Variety can be promoted by supporting firms´ foresight and vision of future technologies (see Kuusi, this volume). The emphasis in policy measures is in influencing innovation *processes* rather than final goals, and in the creation of selection environments and other preconditions for successful innovation.

Reflections of the Evolutionary Approach to Technology Policy Analysis

This paper started by arguing that the specific *economics of technology policy* that is able to deal with globalized techno-economic competition and other economic, social and ecological technology-related problems we currently face, is still in its infancy. An additional argument was that the condition for a qualified economic analysis of technology policy is the understanding of the entirety of technology policy, its constituent components, as well as causal interrelations between components. Such a framework may be of assistance in the understanding of interrelations between different components of technology policy and in the guidance of policy measures. In accordance with this need a preliminary analytical framework for the economic analysis of technology policy is proposed within the evolutionary framework. Some elements of the framework were discussed in more detail but most were not.

In the evolutionary context, technology policy-making is understood as an evolutionary process in which the organizational and institutional structures involved become critical (Nelson and Winter 1982, 384). Some of the main tasks of technology policy in the evolutionary context are the generation of variety and the promotion of selective mechanisms of innovation processes as well as the streamlining of the interaction of actors participating in the innovation process. The promotion of desirable technology trajectories may be one task of policy, likewise is the promotion of firms« access to these trajectories. One example of such a trajectory is environmental technology, which is promoted by regulative and economic

[20] Moral hazard arises because actions that have efficiency consequences are not freely observable and the person taking them may choose to pursue his or her private interests the expense of others (Milgrom and Roberts, 167). Adverse selection refers to information asymmetries among agencies regarding the innate abilities of potential research workers (Dasgupta 1987, 15).

instruments. In future work, other respective trajectories with relevance to social welfare will have to be examined. As in evolutionary economics in general, likewise in the context of technology policy analysis, inspirations from the bio-sciences provide analogies and suggest problems, but hardly supply ready answers. Techno-economic issues have to be understood in their own terms. For example, regulatory systems that are of central relevance to policy issues, differ essentially in biological and societal contexts.

One point of departure this paper is the perceived problems of standard economics in the economic analysis of technology policy. My preliminary conclusion is that at least in the analysis of the components of technology policy discussed in this paper the evolutionary approach gives new insights into the economic analysis of technology policy. However, as the presented examples indicate, the conclusions of evolutionary analysis do not necessarily differ from conclusions of the standard approach although the argumentation differs. The theoretical context of the present paper is the evolutionary economics of technological change. As discussed in Kuusi and Loikkanen (this volume), this is only one emerging school of thought in the broad and diverse literature of evolutionary economics. The problem setting and analysis in other evolutionary and institutional approaches may vary and they also offer new insights into the analysis of technology policy. One challenge for the future development of evolutionary economic analysis is the modeling of technology policy with simulation and other techniques. Thus the identification of the framework and constituent components, discussed in the present paper, is only one necessary step in the elaboration of the more formal analysis of technology policy.

According several observers the importance of technology policy will grow in the future. For example, Vuori and Vuorinen emphasize that especially in the case of national economies in turbulent change, like Finland, the technology policy may even be crucial in the creation of a sound technological basis for a new growth path (1993, 4). The challenge of *the economics of technology policy* is to achieve the analysis in which the theory and empirical phenomena are compatible so that the theory best illuminates the empirical economic problems relating to innovation and technological change. The final goal of the analysis is to give guidance to the shaping of future patterns of technological evolution so that they best serve the social welfare of people.

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TOWARDS A NEW TECHNOLOGY AND INNOVATION POLICY,
Comments to the Article of Torsti Loikkanen

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1) There is no modern industrialized country not pursuing technology and innovation policy in one way or another. Although state interventionism in general is viewed more and more sceptically and despite an increasing shift towards favouring the regulating power of the market, hardly any call has been voiced thus far for the state's withdrawal from the fields of research, innovation and technology. To the contrary: not only is public technology policy considered to be as indispensable as ever for stimulating economic growth, but it has aquired an even growing importance within the scale of state activities. It may be expected that, as knowledge about the complexity of technological innovation increases, state technology policy will gradually develop into an independent policy field (Edquist: 1994). Although there is wide agreement that the state should pursue its own technology and innovation policy, opinions about how such a policy should look like is divided. There are some signs however, that public technology policy will orient itself to a new paradigm.

2) Technology policy is related to the process of technological change. It may be defined as a set of policies involving government intervention in the economy with the intent of affecting the process of technological change through the stimulation of innovations (Vgl Loikkanen 1995:1). Therefore, to discuss public technology and innovation policy, there is a need to clerify the concept of technological change.

Technological change is conventionally characterized as consisting of three different stages: invention, innovation and diffusion. Invention is defined as the stage of production of new knowledge, innovation is defined as the stage of the first application of the existing knowledge within production and diffusion in this model means broadening use of new technologies. The model can be characterised as a "trickle down" or "cascade" model; it is assumed that the extent of fundamental research substantially influences the opportunities for technological innovation within a territory, which in turn determinates the economic growth rate. It is further assumed that in the case of an adequate distribution of resources to fundamental scientific research, technological progress makes it possible to initiate a process of economic growth.

The "cascade" model has often been criticised as being based on a functionalist argument (Schienstock 1994). First of all technological change does not take place according to the linear locig of this model, on the contrary, technological change must be conceptualized as process the outcome of which is not determined but rather open; it is impossible to discover a sequence of clearly delineated stages (Lundvall 1992). Rather innovative activities can be both stimulus and result, consequence and prerequisite. Therefore a broader definition of innovation is now increasingly used,

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which includes all activities of the process of technological change: problems of awareness and definition, the development of new ideas and new solutions for existing problems, the realisation of new solutions as well as the broader diffusion of new technologies.

It is also important to bear in mind that innovations are not very exceptional phenomena; on the contrary, they can take place at any time in all areas of the economy. They therefore have to be conceptualized as ubiquitous phenomena (Lundvall 1992). Thus there is no need to associate innovations with major changes only, incremental changes are also included in the concept of innovation.

3) Using such a broad definition, it is useful to focus on the process of learning through which knowledge and new technologies are created, distributed and used in specific areas. Learning is defined as a collective process shaped by the existing structure of production, by organisations and by institutions. It is assumed that the characteristics of such learning system are central to questions of growth, employment and competition.

In this context it is useful to distinguish between different processes of learning; learning in a more narrow sense such as learning by doing or using and learning in the broader sense such as searching and exploring. Learning in the narrow sense takes place within the production process; therefore it can be refered to as learning by producing (Johnson 1992). Searching and discovering are more complex learning processes, including activities of problem definition and problem solution, which take place in specific institutions. Searching means a process of deliberately choosing and recombining existing knowledge to develop new products and processes. Exploring, on the other hand, means the production of new knowledge for newly defined problems rather than producing knowledge capable of direct technological application.

When using the concept of learning the social shaping of innovations and technology becomes quite clear. This also needs a new understanding of technology. The substantive technology concept must be replaced by a relational one (Rammert 1989). Technology is then defined as an organised system of man and machines in which scientific findings and experiences are applied in the solution of practical problems Abdelmaki and Kirat 1994). In this connection Pacay talks about technological practices (1986: 6) which, apart from a technical dimension also includes both an organisational and a cultural dimension. Technological progress is thus a process of combined techno-organisational and socio-cultural innovation.

Using the concept of technological practice any idea of technological determinism is rejected. The traditional materialistic understanding of technology can be critised because technology on the one side and the "social" on the other side are seen as two separate worlds. Technological development seems to follow its own logic, technology in this approach can be characterised as socially exogenous. The concept of technology practice on the other hand points to the social shaping of technology, it is seens as socially endogeneous. This is true for both processes, the process of creating technology as well as the process of using technology.

Immediately evident when studying the specific structure of modern information technology is the significance of a technology concept extended by the element of practice. Due to the software element which it incorporates in addition to the hardware, this is characterised by a significantly higher degree of "influenceability" by social factors other than traditional technology. This means, in other words that technological progress may not be reduced to the development of substantive technology; rather, the way of structuring the working process via the development of a specific social model, is an endogenous and functionally necessary constituent in the development of technological systems (Naschold 1986: 232).

4) As we have learned so far, technological change also implies a restructuring of the organisation and even a cultural change. But learning as a process of technological change is also influence by the broader institutional setting. The importance of institutions for technological change is particularly stressed by the concept of path dependency (Nelson 1995: 132). Before a new technological paradigm can lead to any substantial rise in productivity, Perez argues (1987), a crisis of structural adaptation must be overcome. A mis-match occurs between new technologies and the old institutional setting. As old institutions correspond to the requirement of the outdated technologic, they have to be change if the new paradigm's productivity potential is to be fully exloited. Institutional change not only refers to the education system, but also to the financial system, the industrial relations system, the governance and regulatory system and so on.

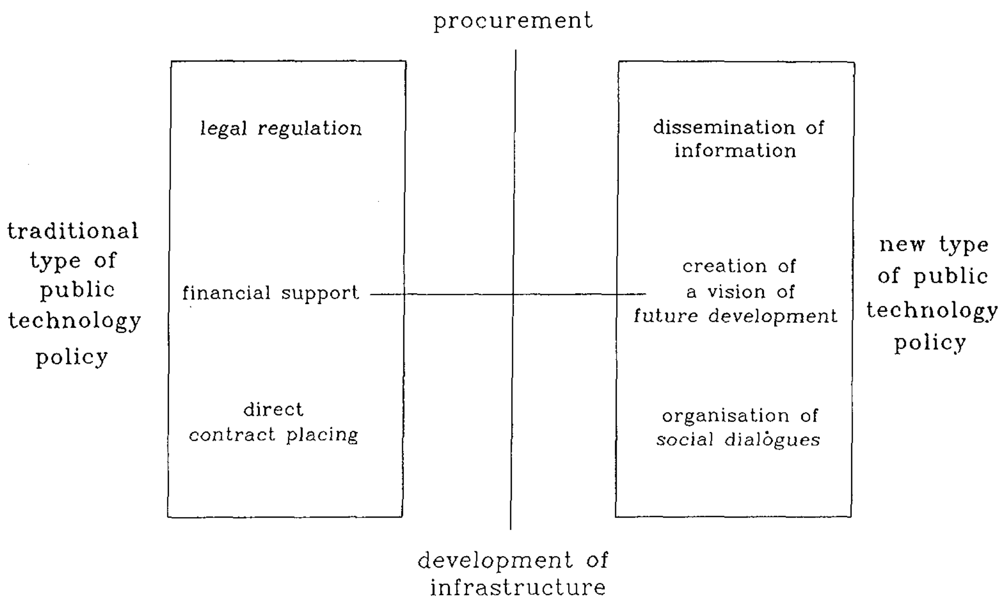
5) The concept of path dependency is often linked with the idea that the fitting of a technology and the institutional setting is moving towards something like optimality (Nelson 1994). This means that step by step through adaptive learning productivity and competitiveness of an economy can be improved. However path dependency may also lead to so called "lock ins" (Johnson 1992, Grabher 1993). In this respect it is useful to distinguish between "structural", "political" and "cognitive lock ins". One can speak of a "structural lock in" when all resources of an economy are bound to the predominant technological develop ment path only and when the whole institutional set-up is tied to this structure. A "political lock in" may be characterized by the fact that a firmly established power structure between the dominant economic actors exists. And we can speak of a "cognitive lock in" if economic actors may be because of earlier successes, adhere to the existing technological path even though its has become less competitive. Because of those "lock ins" economies may lose their competitive edge simply because they can become a hindrance to the search for a new technological paradigms.

6) In an economic crisis, however there are also opportunities for learning to carry out major changes, as it becomes obvious that to overcome the crisis within the traditional development path will not be possible. The distinction between adaptive learning and innovative learning is of importance here (Nystrom and Starbuck 1984). In the case of adaptive learning only a better exploitation of the options of a specific techno-economic development path is possible, while innovative learning leads to fundamental changes caused by a new techno-economic paradigm.

Of course in such a situation of uncertainty economic actors hesitate to take major steps of technological and organisational restructuring, as there is no clear idea of how to procede. Sabel however stresses that even complex changes in an economic crisis are not out of deliberate collective influence although the parties envolved cannot specify the outcome by agreement. He calls this procedure "bootstrapping". It defines bootstrapping as away of reconstructing linked, complex institutions piece-by piece when neither the workable sequences of piecemeal changes nor the precise characteristics of the reconstructed whole are known, and when the risks of staying put are clearly greater than the risks of taking a wrong path (Sabel 1995).

In this situation, Sabel argues, the state can take a leading role. However is becomes quite clear that the role of the state in the process of technological change and industrial adjustment must be changed. It seems to be necessary for public technology and innovation policy to adapt new approaches. The state can no longer assume a leading role in the process of technological change. When it becomes impossible, to anticipate the coming technological and economic order, public authorities cannot define clear strategies for technological development. Instead of claiming the right to stear the process of techno-economic change the state should interprete its role as a coordinator of the various restructuring activities of different economic actors and as a moderator of diverging interests. Such an integrative role must be based on new policy measures: the more traditional measures such as financial support, legal regulation and placing of direct contracts - although the state cannot renounce them - will lose importance compared to what can be called "soft measures" such as the creation of a vision of future developments, the organisation of social dialogues within society or the dissemination of informations concerning the chances and risks of different techno-economic development paths (Schienstock 1994).

In the following figure the predominant measures of traditional and new public technology and innovation policy are presented.



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BEYOND CLUSTER STUDIES - Internationalization of Business and National Policies

Pekka Ylä-Anttila*

Introduction: Innovation System, Industrial Clusters and Internationalization of Business

The usefulness of the notion of an *innovation system* is that innovation is understood as a process where there are sufficient links between various parties spurring the innovation. The goal of *technology policies* is to strengthen these links in order to make use of positive external economies involved in an innovation system. It is exactly these positive externalities which link the notions of innovation system and *industrial cluster.*

The concept of an industrial cluster - as defined by Porter (1990) - implies that the generation of knowledge within a cluster is likely to produce positive externalities and technological spillovers. These give rise to strengthening of the competitive edge of firms within the cluster and, consequently, spur industrial growth. Strong *national* firms are in the core of competitive clusters. It is the *national* characteristics and differences (incl. institutions and technology policies) that explain the international competitive positions and performance of national firms.

Internationalization of industrial *firms* is, to a large extent, based on firm-specific knowledge, which is created in the framework of the national innovation system (NSI) involving - explicit or implicit - co-operation of the state, labour and national firms. Internationalization has, however, proceeded so far that firms are no longer dependent on the national government or labour. The nation as a central concept or unit of analysis has become problematic - and so has the role of national industrial and technology policies. Multinational enterprises (MNEs) are an essential part of national innovation systems, but their role has changed in many important ways.

Setting the Context and Posing the Questions

Since the mid-1970s the Finnish industrial structure has been rapidly moving from factor-driven towards technology-driven industries. At the same time the knowledge intensity within the traditional strong clusters (forest and base metal) has increased through diversification to new product areas and upgrading of production processes (see Hernesniemi - Lammi - Ylä-Anttila, 1995 and 1996). The increase in technology intensity coincides with the rapid internationalization of business which started to accelerate in the early 1980s.

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All industrial clusters in Finland - with the exception of the two defensive ones (foodstuff and construction) - have been internationalizing very fast during the last 10 - 15 years. Also the firms within the forest and basic metals clusters - whose competitive edge originally was based on domestic raw materials and domestically developed or upgraded technologies - have increasingly internationalized their production. Internationalization of these firms has partly been based on vertical integration or resource seeking direct investments, partly on firm- specific process knowledge developed within the clusters.

According to Porter (1990) outward FDIs are an indication of competitiveness in the same way as high export market shares. Large scale inward FDIs - in Porter's view - indicate a lack of national firms' capabilities to defend their market shares against foreign firms. From the point of view of the national policies and performance of the national system of innovation the issue is, however, much more complicated. That is due to the fact that it is not only production - but also knowledge generating activities of firms - that are increasingly carried out outside national borders.

There is growing evidence that since the late 1980s - following the internationalization of production, marketing, finance and logistics operations - also the R&D activities of MNEs started to internationalize rapidly (see Fors, 1993; Heum and Ylä-Anttila, 1993 and Puhakka, 1994). R&D is, however, clearly less internationalized than other activities of MNEs. A crucial part of the national innovation system - the innovative activities of industrial firms - has, nevertheless, become more and more international. Related to this, there are several important questions to be raised.

Is the role of the national framework becoming weaker and even futile? Or is it just the other way round: have the closed national systems reached their peak, and will only decline if they don't get stronger support from foreign influences and connections? (cf. Vuori and Vuorinen, 1993).

How will the rapid internationalization of business affect the performance of the national innovation systems and national technology policies? To what extent have the firms of small countries like Finland actually internationalized? What is the role of existing strong national clusters in future industrial growth? Or is it only the transnational clusters that will grow? Have the firms been moving their R&D departments abroad? Or is the national framework still important for knowledge creation and learning processes of internationalized firms?

Beyond Cluster Studies: Towards Local and Global Determination of Competitiveness

The national agenda clearly dominates the Porterian cluster analysis. The determinants of a nation's international competitiveness are analysed in the framework of the *home country "diamond"*, which is the source of competitive advantage of national firms. The competitive advantage of a firm depends on four key determinants: factor conditions; demand conditions; firm strategy, structure and rivalry; and related and supporting industries. At best these factors constitute an entity, an industrial cluster, in which parts strengthen each other due to positive external economies and technological spillovers.

According to the Porter model an internationally operating firm needs to have a sustainable competitive advantage based on successful utilisation of various components of the home country diamond. Domestic firms build their international success - exports and engagement in foreign direct investment - on this home base.

It is the national characteristics and differences that explain the international competitive positions and performance of domestic firms. However, globalization of the world economy is leading to tensions between national differences and international convergence. On the one hand, there seems to be a lot of differences in the "cultures of capitalism" reflected, e.g., in the difficulties in carrying out cross-border mergers successfully even in Europe (see Cable, 1995). On the other hand, there is a growing tendency for global networking, taking advantage of cost and skill differentials by utilizing flexible production technologies and relocating not only production, but also product design and R&D activities (see Reich, 1991).

The traditional concept of "national competitiveness" and related industrial policies of enhancing exports or import competing activities have lost much of their relevance, although they are still popular among national governments. Competitiveness is no longer simply a trade issue. More than that national competitiveness is about creating an attractive business environment: high quality infrastructure, competitive markets, stable macroeconomic conditions, good technological infrastructure and skilled labor (cf. Cable, 1995, and Hernesniemi - Lammi - Ylä-Anttila, 1996).

The model of competitive advantage based on industrial clusters as well as on the idea of "competing nations" is much closer to the latter approach than to the traditional export promoting approach to industrial policy making. Nevertheless, the Porter analysis obviously neglects the strengthening role of multinational companies by taking nations as the only relevant geographical entity of analysis.

As a consequence of internationalization of business, national systems of innovation and national industrial clusters are changing into two directions: regional and international. The national aspect in policy making will be of less importance. Some of the national institutions have been or will be replaced by international ones, particularly at the European level, as the economic integration deepens. On the other hand, the role of regional systems will increase, since learning and networking are always, to a large extent, local processes. Regional systems will be of particular importance for the diffusion of technological knowledge. In public policies much more attention will be given to the processes of knowledge access and distribution.

Internationalization of business is not fully taken into account in the NSI approach and public policies based on it. That becomes clear when we consider what has happened during the last few years among the largest industrial firms which are defined to be the key elements in the national innovation system. Industrial R&D is very heavily concentrated in large firms, especially in small economies (see Heum and Ylä-Anttila 1993b). In Finland, for example, the twenty largest corporations account for about 90 % of total domestic R&D. Furthermore, an increasing part of corporate R&D is conducted outside national borders.

Internationalization of Industrial Activities

FDIs of large industrial firms in Finland have been growing fast since the mid-1980s. Currently, close to 50 % of the employment of the large manufacturing firms is outside the national borders (see Heum and Ylä-Anttila 1993a and b, and Table 1).

As Table 1 reveals most of the largest firms which originally grew and created their competitive advantages as parts of the national innovation system or national industrial clusters have become multinationals and are, in fact, parts of transnational clusters. Internationalization is an important source of competitive advantage for firms operating in highly specialized market segments, like many of the Finnish firms do.

Many of the largest industrial firms, besides being multinationals, are also the most important R&D spenders - not only within industry, but also within the whole (national) innovation system. R&D investment of the company with the largest R&D budget in Finland (Nokia) equals some two thirds of the total university sector's research spending. The aggregate R&D expenditures of the twenty largest industrial firms is as much as about two times that of the university sector.

Table 1. Total and foreign employment in the 20 largest Finnish manufacturing companies in 1983 and 1993

	1983			1993		
Company	Total employment	Employment in foreign subsidiaries	%	Total employment	Employment in foreign subsidiaries	%
Repola	18512	1300	7	27215	10886	40
Nokia	23651	4146	17,5	25801	11988	46,5
Kone	13137	8700	66,2	20710	17576	84,9
Kymmene	16087	2426	15,1	16462	4092	24,9
Outokumpu	10089	141	1,4	16073	8179	50,9
Valmet	15371	1969	12,8	15716	5740	36,5
Enso	15315	1500	9,8	14071	2036	14,5
Metsäliitto	7891	590	7,5	13084	2844	21,7
Ahlström	12472	1796	14,4	12863	7019	54,6
Neste	7076	1489	21,0	12541	5552	44,3
Kemira	8159	200	2,5	11446	5152	45,0
Huhtamäki	4698	311	6,6	11190	8178	73,0
Partek	6200	531	8,6	9428	6039	64,1
Rautaruukki	7712	120	1,6	9060	1951	21,5
Asko	3800	1227	32,3	8343	4117	49,3
Amer	2102	454	21,6	5594	4138	74,0
Cultor	4397	200	4,5	5159	1709	33,1
Orion	4106	290	7,1	5029	341	6,8
Tampella	7611	613	8,1	4592	2717	59,2
Hackman	2006	17	0,8	3432	1646	48,0
Total	190881	28020	14,7	247809	111900	45,2
Share in total manufacturing, %	35	77		66	86	

Table 2. Internationalization and R&D expenditure in 20 largest industrial corporations in Finland, 1993

Firms	Foreign employment	% of total employment	R&D expenditure	R&D, % of sales
Repola	10886	40	254	1
Nokia	11988	47	1472	6,2
Kone	17576	85	145	1,3
Kymmene	4092	25	78	0,5
Outokumpu	8179	51	450	2,8
Valmet	5740	37	295	2,8
Metra	11182	77	259	2,5
Enso	2036	15	93	0,7
Metsäliitto	2844	22	84	0,7
Ahlström	7019	55	432	4
Neste	5552	44	477	0,8
Kemira	5152	45	237	2
Huhtamäki	8178	73	194	2,4
Partek	6039	64	125	1,9
Rautaruukki	1951	22	91	1,3
Asko	4117	49	75	1,2
Amer	4138	74	29	0,4
Cultor	1709	33	70	1,1
Orion	341	7	272	7,6
Tampella	2717	59	105	2,6
Total	121436	46	5237	1,9
Share in total manufacturing	93,8		90,3	

In spite of the rapid internationalization most of the Finnish multinationals have so far had a foothold in the home country in the form of the headquarters and R&D activities (see Puhakka 1994). However, the growth of foreign located R&D has been fairly rapid in recent years. As Table 3 displays in the group of largest Finnish manufacturing companies as much as one third of R&D is contucted outside national borders. Interestingly enough the share of foreign R&D is much bigger in the group of knowledge intensive engineering firms than in the group as a whole. The big firms have not, however, to any large degree moved their R&D departments abroad. Rather, the increase of foreign located research and development is due to acquisitions of fairly R&D-intensive foreign firms (see Säynevirta and Ylä-Anttila 1994 and Hölsä 1994).

Table 3. R&D expenditure in a sample of Finnish multinational companies in 1990 and 1992

	All firms (N=28)		Engineering industry (N=15)	
	1990	**1992**	**1990**	**1992**
Turnover (million FIM)	84631	87628	37713	40651
R&D expenditure (million FIM)	1502	1492	837	858
thereof:				
- domestic (%)	74	69	61	54
- foreign (%)	27	31	39	46

Source: Puhakka (1994)

According to conventional wisdom the internationalization of industrial firms contributes positively to the productivity and competitiveness of the domestic units of the multinationals and, hence, the growth of the home economy. The effect of internationalization on productivity works through R&D and other efforts to cultivate firm-specific assets promoting competitiveness. Foreign production allows firms to grow larger compared to what otherwise would have been possible. Thus, R&D expenditures and other expenses to promote and upgrade the industrial competence may be distributed over larger sales volumes (see, e.g. Swedenborg 1982 and 1991).

There is a risk, however, that the internationalization of national firms may reach the point where the industrial and technological base of the home country is gradually eroding. There is some evidence from the Swedish MNEs which seems to indicate that this process may be about to happen (see Svensson 1993 and Fors 1993). The Finnish data does not allow any firm conclusion so far, but, in any case, the rapid internationalization of industrial firms and that of R&D activities in particular, pose a major challenge for industrial and technology policies. The conventional industrial and technology policies in the national framework are not adequate. National policies still matter but they have to be redesigned.

Towards New Industrial and Technology Policies[1]

Regardless of what conclusions on the home country effects of FDI could be drawn on the basis of the current evidence could be drawn, there is hardly any adequate reason to try to enforce regulations on FDI, or attempt to control the foreign operations of domestic multinationals. Policy efforts should rather, on sound industrial grounds, attempt to promote the strength and competitiveness of the domestic industrial base to attract internationally operating firms, whether they are of domestic or foreign origin.

Subsidies and compensatory policies are not tools of a modern industrial policy maker. Although the old argument of an infant industry has some truth to it, it has been used in many industrial countries mainly to protect established but uncompetitive industries, thus postponing the necessary and natural restructuring.

The goals of the new industrial policy are (1) to guarantee the functioning of a free market, and (2) to create advanced and specialized factors of production. Public market intervention is justified only if there is a clear market failure. Externalities are one of the reasons why a competitive market might not reach a comparatively efficient outcome. Apparent examples are education and basic research; a higher knowledge level increases national wealth as the value-added content of production increases, but these investments are not necessarily rational to a business enterprise due to the mobility of labor.

As the factors of production have become internationally mobile and international competition is freed, the key policy issue is: *How can a country be made an attractive home base for internationally competing enterprises?* Industrial policy can be used to improve the operating environment and factor conditions, but the market decides which companies survive.

The principles of new industrial policy - promoting competition and creating advanced factors of production - are widely accepted in the industrialized countries. The method of implementation, however, is a matter of dispute.

Porter's model can be used as a frame of reference. It illustrates the way in which competitive strength is born. One of the main messages of cluster analysis is that the scope of industrial policy should be broad. It should not involve only industries or business enterprises; it should not only reallocate existing resources, but should also focus on the creation of future factor conditions.

The role of industrial policy is depicted in figure 1. The economic and industrial policies set the operating environment of private enterprise. The effects of industrial policy are indirect. Direct subsidies distort competition and are harmful in the long run. The public sector can not create competitive advantage - it can only set favorable preconditions.

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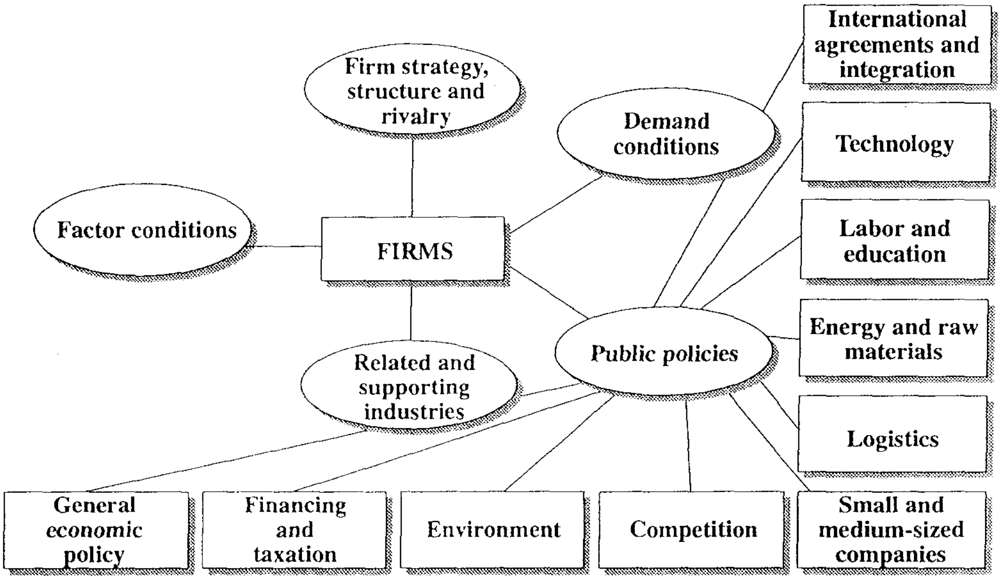
1 Based on Hernesniemi, Lammi and Ylä-Anttila (1996).

Figure 1 Determinants of competitive advantage and the components of economic and industrial policy



Competition policy is used to establish a competitive environment in which companies formulate their own strategies. Competition is one of the main driving forces behind innovation and upgrading of existing products and processes as well as organizations.

Technology and education policies are used to create a pool of advanced and specialized factors, which are the main sources of sustainable long-term growth.

Environment, taxation and *trade policies* have a significant effect on demand conditions. The public sector can act as a demanding, sophisticated, and anticipatory customer by setting norms and standards

The NSI approach as well as industrial clusters - in spite of their inherently national character - offer a framework for contemplation of new industrial and technology policies required by changed international economic environment. However, there has to be a clear shift of emphasis from direct to indirect measures.

According to systems approaches competitive advantages are born in closely interrelated firms and branches that form industrial networks or development blocks. Traditional policies seeking to affect industry and industrial firms directly (subsidies) are of secondary importance and, in fact, nearly always harmful. Public policies can have an even greater indirect impact via elements that foster technical progress and competitiveness of firms. The main policy goal should be the influencing of quantity and quality of resources emerging in the future. The key issue is to understand the industrial dynamics. Industrial development blocks or clusters as well as systems of innovations are constantly changing. This implies that consciously created factors of production and competitive advantages are more important than inherited ones.

As technological knowledge is to a large extent tacit, much of the communication and technology transfer take place in various kinds of networks. It is the task of technology policies to enhance the kind of institutional set-up that promotes the formation of networks, whether regional, national or international.

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THE GROWTH PATTERN OF SWEDISH INDUSTRY 1975 - 1991

Charles Edquist* and François Texier*

Introduction[1]

Sweden has fallen down the OECD "welfare league" during the past 25 years; from position three/four in 1970 to position sixteen in 1995.[2] Sweden's high level of unemployment, reached in the early 1990's, threatens to become permanent at about 10 percent. The main reason why "real" jobs must be created to ameliorate the current Swedish situation is simply that the alternatives - labour market and social policies - are too expensive to mitigate the consequences of unemployment, and they provide no long term solution. Therefore everyone seems to agree that what Sweden needs is economic growth and employment growth.

A lot of proposals for achieving growth have been aired in the debate over the latest year or so. Some examples include lower value added taxes on services, lower wage taxes, lower overall taxes, a change from wage taxes to environmental taxes, a more flexible labour market, more co-operation between the labour market parties, etc. Both political parties and interest groups have taken out their old proposals and - suddenly - transformed them into instruments of growth. This has often been done without even trying to argue *how* and *why* these proposals would lead to growth or employment generation in the Swedish economy.

Innovation, Growth, and Employment

What, then, are the long term sources of growth? Are there different kinds of growth? Which types of growth lead to more jobs and which do not? Are there unexploited sources of growth as a consequence of the current Swedish economic situation? These questions should be at the centre of the debate, but they have hardly even been touched.

Increased productivity is the only way a country can raise its material standard of living and welfare substantially and sustainably over long periods of time. It can give us more education, more health care, more and better libraries, more material things

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[1] We are grateful for comments on an earlier version of this paper from Mats Bladh, Johanna Forsell, Patrik Hidefjäll, Maureen McKelvey, and Ulf Sandström. We also want to thank Dawn House for editing the text.

[2] However, Sweden climbed from positon seventeen to sixteen between 1994 and 1995. The only other radical change since 1975 is that Japan has climbed from position seventeen in 1970 to position six in 1995.

and/or shorter working hours. Increased productivity can be used and distributed in many different ways. It is not an end in itself but a means to achieve welfare in a wide sense, including self-realization and satisfaction of non-material needs. It is one of the most important economic variables. As Paul Krugman expressed it, "Productivity isn't everything, but in the long run it is almost everything" (1992: 9).

As shown in the ratio below, production is measured in value added or sales value and labour input in number of employed or number of hours worked. Labour productivity is simply production per worker, per day or hour worked. If labour productivity increases it is because production increases or because labour input decreases - or both. In other words, production does not necessarily increase if productivity increases, i.e., productivity growth is *not* the same thing as economic growth.[3] Productivity growth can also be used to increase leisure time or lead to unemployment. However, most economic growth is still based upon productivity growth.

$$\text{Labour productivity} = \frac{\text{Production}}{\text{Labour input}}$$

Grossly simplified, it can - on the basis of the findings in the "growth accounting" literature - be argued that the main *sources* of labour productivity growth in industry in industrialized countries are the following:

- more capital per employed (capital accumulation),
- better education, and
- the so-called "residual".

Of these three sources, the residual accounts for between 50 and 60 percent of productivity growth according to most growth account studies.[4] When the remaining 40-50 percent of productivity growth sources are examined, a better education is often a larger source than capital investment, accounting for something like 25 percent of productivity growth.[5] Hence the residual is by far the most important source of increased labour productivity - which in turn is the most important source of increased welfare in the long run. The second largest source of productivity growth is better education. Both these sources have some relation to "knowledge" in a wide sense. Capital investment is the third most important source of productivity growth.

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[3] Neither is it the same as increased competitiveness, although the latter is strongly influenced by productivity growth.

[4] This is a broad generalization of the findings in the growth accounting literature made in Edquist (1993). The generalization is based on growth accounting analyses made for long periods (decades) in this century for the USA, Canada, Japan, Denmark, France, West Germany, Italy, the Netherlands, Sweden, and the UK (Åberg 1984: table 6.1, Denison 1985, Abramovitz 1989, Baumol et al. 1991: 175-6). An important point of criticism against growth accounting is that it treats the sources of growth as independent from each other.

[5] Sometimes they are clustered together however, "capital accumulation" then includes investments in "human capital" (i.e. education and training).

What then is the residual?

According to Denison (1985: xvi, 28-32), the residual is the same as "advances in knowledge". By this he means technological knowledge, managerial knowledge, and organizational knowledge. It does not matter whether the knowledge has been produced domestically or abroad, through organized research, by individual inventors, or through experience or learning-by-doing.[6] But knowledge as such does not contribute to productivity growth. It must, of course, be implemented in production in order to influence productivity, i.e., the ability of firms to absorb knowledge is crucial. Knowledge is implemented into production through *innovations*. This means that innovations are the most important source of labour productivity growth.[7] The residual is often also called "the technology factor" or "technical change".[8]

It is important to keep in mind that the forces that influence the residual are treated as exogenous by traditional economic theory, including traditional growth theory. This means that traditional theory has very little to say about the source of half of productivity growth. This in spite of the fact that most economists agree with Krugman that productivity growth is the most important economic variable.

These problems are partly mitigated with the development of the so called 'new growth theory' during the last decade. In these theories technical change (process as well as product innovations) and human capital (competence and learning-by-doing) are endogenous variables.[9] Innovations and learning are placed in the centre of focus to an even larger extent in the so called 'systems of innovation approach' which has also emerged during the last decade. In this approach the determinants of innovation are also considered to be exogenous variables, which is not done in the new growth theories.[10]

"Economic growth" is often considered to be the panacea for solving the unemployment problem; higher growth is assumed to create more jobs. However, the relation between growth and employment is certainly not that simple and unambiguous. If production increases, i.e., if economic growth is created, the employment implications can be quite different depending on the nature of that growth. The "employment intensity of growth" might differ between various "kinds" of growth.

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6 Hence knowledge that is created through learning processes like "learning-by-doing", "learning-by-using" and "learning-by-interacting" are included.

7 The residual is also equal to total factor productivity. Total factor productivity is the ratio between production volume and the input of all factors of production. Total factor productivity hence measures growth of production which cannot be accounted for by increased quantities of inputs of the production factors.

8 Given its content, a more proper name would be 'the innovation factor'; innovation then including not only technological innovations but also organizational (including managerial) ones.

9 This development was done, for example, in Romer (1986), (1989), and (1990), Lucas (1988) and Grossman and Helpman (1991).

10 Two recent books in the systems of innovation approach are Lundvall (1992) and Nelson (1993). The emergence of this approach is treated in some detail in Edquist (forthcoming).

Which kinds of growth, then, lead to more jobs and which do not? This question can be discussed most effectively by distinguishing the different kinds of growth by the kind of innovation that is the source of the growth.[11] Innovations can be organizational or technological and the latter category can be divided into product innovations and process innovations.

We have seen that innovations are the source of much productivity growth - and thereby also behind most economic growth. Innovation-based productivity growth can be achieved by organizing work in a more productive way (organizational innovations), or by improving real capital through technical change (technological process innovations). Both these types of innovation influence *how* (old or existing) goods and services are produced.

Technological and organizational *process* innovations are often necessary for maintaining relative competitiveness. But they do not create new jobs. On the contrary, increased productivity achieved in this way means, by definition, *fewer* jobs for the same production volume. Only if production increases enough to compensate for the jobs lost through the innovations can net employment increase. These are the so called compensation mechanisms.

The Swedish pulp and paper industry is a good example. In this sector very large process investments which involve process innovations and increased production are currently being made. But no new jobs will be created; the growth generating investments will instead reduce the number of jobs. In other words, growth does not necessarily imply more jobs!

There are also technological *product* innovations. These are new or better goods or services which have not previously been produced. Here it is a question of *what* is produced.

Technological process innovations are new goods that are used in the process of production. They have previously been material product innovations. In other words, these goods appear in two "incarnations" in the economic system. An industrial robot is a product innovation when produced by ABB in Västerås and a process technology when used by Volvo in Göteborg. The same artefact can be a product as well as - in a later stage - a process innovation.

Within the production sphere, there are also other important kinds of relations between material product and process innovations. In some cases the production of new products requires new process technologies. An example is the production of a new kind of integrated circuit with a smaller line breadth. It absolutely requires new lithographic and other process technologies. Other product innovations do not require new process technologies. An example could be a new kind of pump - which can be produced in the same mechanical factory as old kinds. A third kind of relation along this dimension is when the same - or a very similar - product is produced with radically different process technologies. An example is human growth hormone - previously extracted from human brains and now produced through genetically

11 Hence this discussion excludes growth based on capital accumulation and better education.

engineered cells. Product innovations may also emerge as a result of, or in close relation to, new process technologies.

A considerable part of industrial R&D goes to the development of new and/or better products (rather than processes), although this figure varies between countries.[12] Intuitively, we expect there to be more new goods - i.e., more product innovation - in R&D intensive sectors of manufacturing than in other sectors.[13] Examples are electronics and pharmaceuticals.

The production of R&D intensive goods is also positively correlated to high productivity and high productivity growth.[14] We also expect the market for new goods to grow faster than for old goods. As a consequence we expect a "mediated" correlation between sectors with a high R&D intensity (and a lot of product innovation) and sectors with a rapid market growth.

The historical process of economic change is characterized by job "destruction" resulting from productivity increasing process innovations and organizational innovations - while new jobs have been created through product innovations.[15] What makes product innovations so interesting in a situation of large unemployment is that they might lead to more jobs *as well as* higher productivity. Here growth and more jobs go hand in hand!

In other words, some kinds of productivity growth are compatible with job creation[16], other types mean that jobs disappear. As regards the macroeconomic consequences of innovation these differences are crucial.

The category of innovation is extremely complex and heterogeneous. It is therefore necessary to make analytical distinctions between different kinds of innovations. The main one proposed here is the one between product and process innovations. Others might certainly be fruitful. Some arguments for the usefulness of the one made here are the following:

1. The patterns of diffusion are very different for technological product and process innovations. For example, Swedish industry is very good at the diffusion of process

12 Depending on how one counts, this figure is between 75 and 90 percent for Sweden (SCB 1991: Table 4). In 1985 68 percent of industrial R&D was spent on the development of new products and product changes in the USA. The figure for Japan was 36 percent (Mansfield 1988:1771). The rest of industrial R&D was in all three countries spent on the development of new processes and process changes.

13 An R&D intensive sector has a high ratio between R&D expenditures and production value or value added.

14 This has been shown in Edquist and McKelvey (1992), Edquist (1993b) and Tyson (1992: 35). Learning curves are also steeper for R&D intensive goods, and their development and production are often associated with positive externalities. This means that a country with a relatively large production of R&D intensive goods can be expected to experience a higher productivity growth (and a higher economic growth) than other countries.

15 These issues are discussed in Edquist (1996) with regard to goods production as well as service production.

16 It must be pointed out here that this concerns productivity as it is measured, i.e., in price-based value terms.

innovations and bad at the diffusion of product innovations. The pattern is the reverse for the USA. Japan is good at both.

2. The determinants behind these differing patterns of diffusion are different between the two categories.
3. Process innovations may be technological as well as organizational and product innovations may be goods or services.
4. Only some product innovations become process innovations in a later incarnation.
5. The consequences for productivity are different and work through different mechanisms.
6. The consequences for employment differ.[17]

The Pattern of Innovation, Growth, and Employment of Swedish Industry

Let us, in the perspective outlined above, deal with Sweden's recent experiences with various kinds of innovation.

Swedish industry has traditionally been extremely successful with diffusing process innovations in traditional sectors[18]. For example, Sweden is the only 'old' industrial country that has managed to compete with Japan in diffusing automation technologies in the engineering industry. During recent years the degree of diffusion of organizational process innovations seems also to be fairly advanced in Sweden, although there is a severe lack of systematic data here. The rapid diffusion in Swedish industry of these two kinds of innovations have fostered productivity and competitiveness, but reduced employment (per unit of output) (Edquist 1989, 1992).

With regard to product innovations there is, however, a severe structural problem in the Swedish national system of innovation. As we saw above, product innovation is a matter of what is produced. It is true by definition that product innovation is a matter of introducing *new* products. Companies with a high R&D intensity conduct their business in areas with high technological opportunities. Companies with a low R&D intensity are more inclined to reduce production costs by process innovations. New products simply emerge more often in R&D intensive (or hi-tech) industries, i.e., in industries where their is a large effort to create new products. In a recent survey it has also been shown that high R&D intensity companies in Sweden are more oriented towards creating new products than reducing costs, and that low R&D intensity

[17] The bases for the first two arguments are Edquist and Jacobsson (1988) and Edquist (1990). The others are dealt with in Edquist (1996). With regard to argument number six, we would like to quote from a study of innovation and employment in Italy: "The overall impact of technology on employment in Italian manufacturing is found to be caused by the dominant role of process innovations and embodied technical change in firms' innovative activities. An opposite labour-increasing pattern can be found in some sectors characterized by higher design and engineering intensities and higher percentages of product innovations" (Vivarello, Evangelista, and Pianta 1995:1).

[18] This was shown in detail in Edquist and Jacobsson (1988). More recent data on this have been presented in Carlsson (1995: 6) and by the United Nations Economic Commission for Europe (1996).

companies are more oriented towards reducing production costs than creating new products (NUTEK 1995: 20).

Let us briefly summarize the results of a study of the proportion of R&D intensive products produced by Swedish industry, as compared to the averages of the OECD countries (Edquist and McKelvey 1995). One of this study's conclusions is that Sweden is negatively specialized in the production of high tech products, relative to other OECD countries. As a matter of fact, in 1990 the proportion of R&D intensive products in Swedish manufacturing production was only 71 percent of the OECD average. A general trend shows that from 1975 to 1990, Swedish industry has become decreasingly specialized in this respect (ibid.: 10 and figure 1). In this paper we will go somewhat deeper into the issue of the growth pattern of Swedish industry. We will investigate the performance of Swedish industry with regard to what we call "growth products".

In line with OECD criteria, the following sectors/product groups were classified as high tech in Edquist and McKelvey (1995):

ISIC 3522	Drugs and Medicine
ISIC 3825	Office and Computing Machinery
ISIC 383	Electrical Machinery and Components
ISIC 3845	Aircraft
ISIC 385	Professional Goods

Using the STAN[19] database we identified those product groups for which production had empirically grown most rapidly during the 1975-91 period in the OECD area as a *whole*. We call these products *growth products*. They are:

ISIC 342	Printing and Publishing
ISIC 3522	Drugs and Medicine
ISIC 356	Plastic Products, nec[20]
ISIC 3825	Office and Computing Machinery
ISIC 3832	Radio, TV, and Communication Equipment
ISIC 3839	Electrical Apparatus, nec
ISIC 3845	Aircraft

(Note: 383 (Electrical Machinery and Components) is normally divided into several sectors. However in STAN 3832 plus 3839 equals 383 as a whole.)

A comparison shows that all the R&D intensive product groups except professional goods were among the growth products. (See also the note above.) Two of the growth product groups (Printing and Publishing and Plastic Products, nec) were not among the R&D intensive product groups. Obviously, the correspondence between growth products and high tech products is large.[21]

19 STAN is an industrial database provided by the OECD, allowing cross country comparisons.

20 nec = not elsewhere classified.

21 A similar conclusion was reached by Stenberg (1995: 109), though it was formulated by him in a fairly different way than here. Let us therefore quote him at some length: "In the OECD countries as a whole

Mobile phones and equipment for such systems and computers are examples of growth products. Pulp paper, steel, ball bearings, and ships are not. In order to show more specifically what the growth products are, we have here included an appendix which indicates the content of the various ISIC categories in some detail (appendix 1). It must be kept in mind, however, that all specific products listed there are not necessarily growth products. They are only growth products "on the average", i.e., at the more aggregated level. Similarly, there are, of course, specific products that are growth products also in ISIC categories at the three- and four-digit levels which are not listed in the appendix.

The proportion of Swedish industrial production that occurred in the growth industries was about 76 percent of the OECD average in 1990. In 1975 this proportion was 100 percent. In other words, Swedish industry had the same specialization as the OECD in 1975, but lost it from 1975 to 1990 (STAN).

Swedish industry is, accordingly, "stuck" in old, traditional sectors and does not pursue concerns where the growth opportunities are largest. This is shown in figure 1 (in current prices). The figure shows the growth in production of growth products and other (non-growth) products for the OECD and for Sweden from 1975 to 1991.

By definition the production of growth products grows faster than other products for the OECD as a whole; about twice as fast in current process. In Sweden the value of the production of growth products has grown much more slowly than in the OECD as a whole. As a matter of fact, the growth in the production of growth products in Sweden is not much faster than the growth in the production of non-growth products. Hence the situation with regard to specialization in growth products has deteriorated for Swedish industry during the last decades. [22]

Let us look at the employment side of the Swedish growth pattern. Figure 2 shows the growth in employment in the production of growth products and of other industrial products for all OECD countries and for Sweden between 1975 and 1991.

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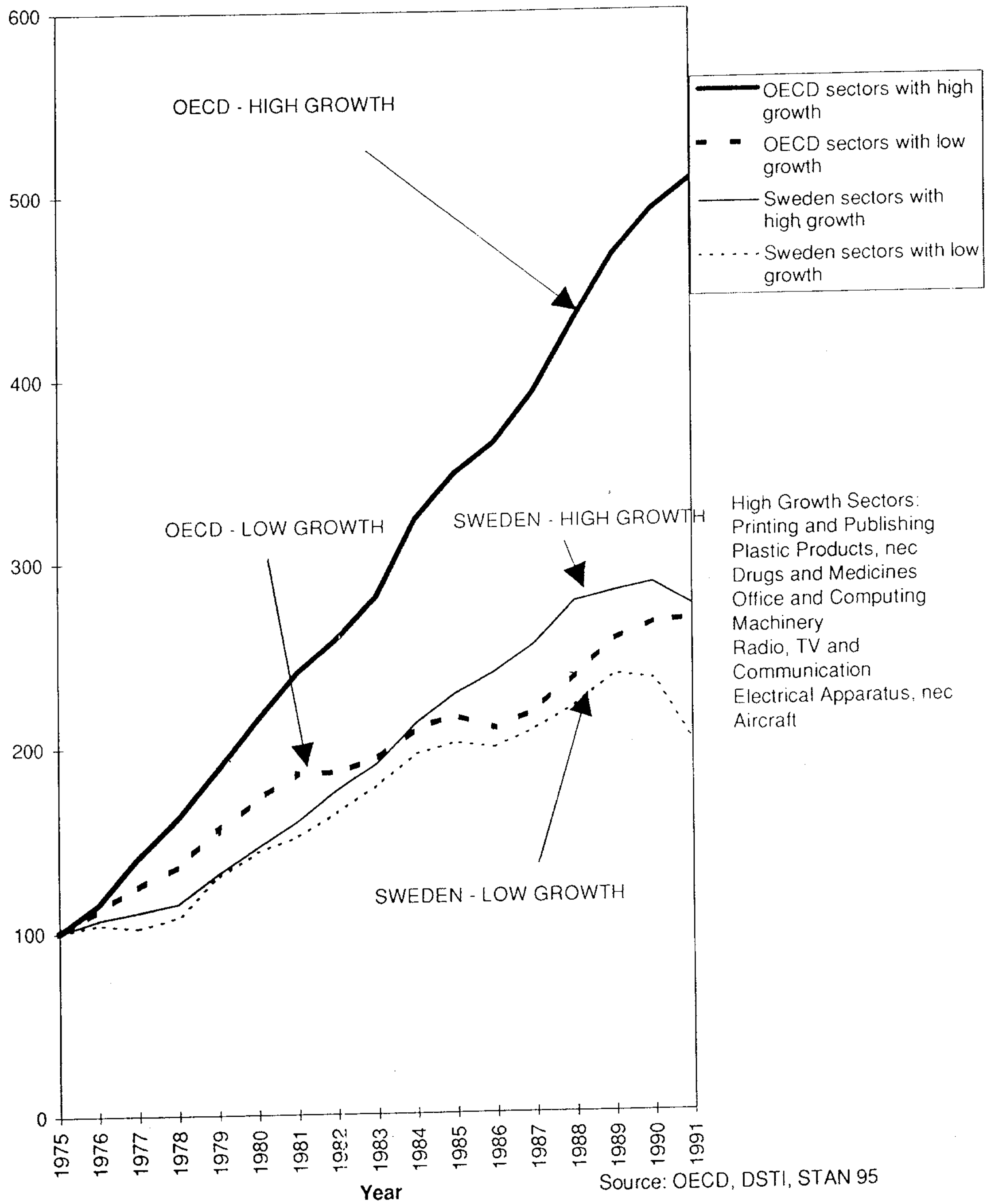
employment in the high technology industry increased by 7 percent during the 1980s, while employment in industry as a whole decreased approximately as much. Still the high technology industry accounts for less than a fifth of industrial employment in the OECD countries. It should also be noted that, among those industries that have a favourable employment growth, there are also industries that are not considered to be high technology industries, primarily the plastics products industry and and the printing and publishing industry" (Stenberg 1994: 109; our translation).

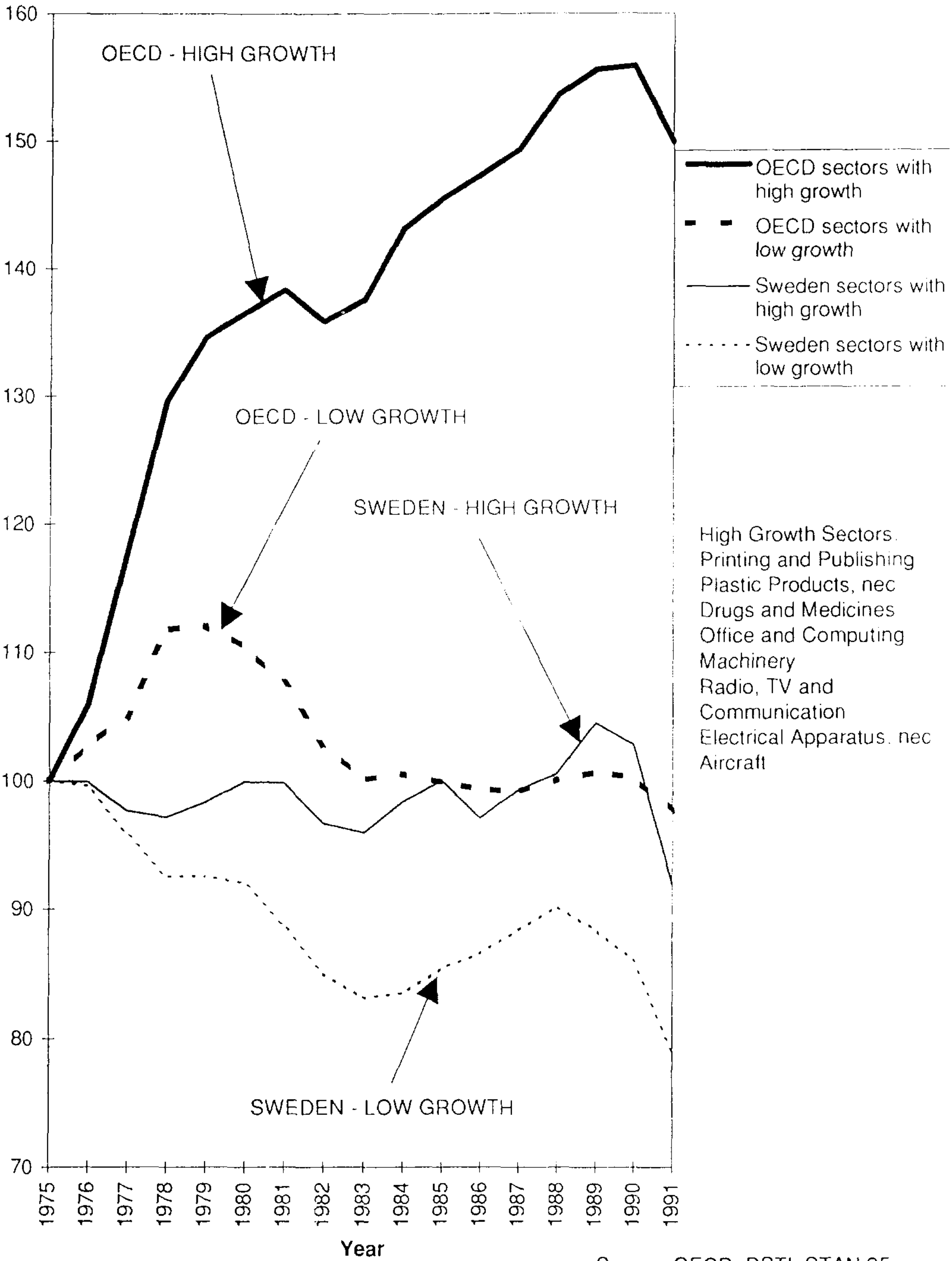
[22] It would be interesting to compare the Swedish pattern also to other individual OECD countries, and not only to the OECD average. Is there, for example, any other OECD country with a similar growth pattern as the Swedish one?

Figure 1. Production Growth in Sweden and in the OECD (relative change in current 1985 price)



Source: OECD, DSTI, STAN 95

Figure 2. Employment Growth in Sweden and in the OECD (relative change)



High Growth Sectors.
Printing and Publishing
Plastic Products, nec
Drugs and Medicines
Office and Computing Machinery
Radio, TV and Communication
Electrical Apparatus, nec
Aircraft

Source: OECD, DSTI, STAN 95

Employment in the growth sectors has grown by 50 percent in the OECD as a whole during the period. These jobs are characterized by high productivity and relatively high wages. In Sweden there were approximately 210 000 jobs in these sectors in 1975 and 190 000 jobs in 1991. In the rest of industry the number of jobs were about the same in 1975 and in 1991 for the OECD as a whole, while the number of jobs had decreased by 20 percent in Sweden.[23]

It is often noted that industrial employment has gone down in the industrialized countries ever since the 1950's and 1960's.[24] In this context it is interesting to note that this is certainly not true for all of industry; the employment increase in the growth industries was 50 percent. In other words, there are obviously important differences between sectors with regard to the creation of employment. Hence it matters a great deal for employment (and unemployment) in which sectors a country's industry is specialized.

This has to do with the fact that many products in the growth industries are new ones, i.e., product innovations. We saw earlier in the theoretical discussion that the employment implications of product innovations on one side and of technological and organizational process innovations on the other are quite different.

The main difference in figure 2 is between the growth in employment in the growth sectors of OECD member countries as a whole and of Sweden. In Sweden, employment in the growth sectors decreased by 30 000 jobs between 1975 and 1991. This must - theoretically - be reflected either in slower production growth in the growth sectors in Sweden or in increased productivity - or both. In reality it is both as shown in figure 3.

Productivity was previously defined as the ratio between production and employment, therefore productivity growth is the ratio between production growth and employment growth. On the horizontal axis (x-axis) of this graph, we have production growth, while the vertical axis (y-axis) shows employment growth. Productivity growth is hence visualized in sectors identified by the lines Production growth (x) equals Employment growth (y) times Productivity growth (a), or x=y*a. We can then see productivity growth increasing clockwise, as the arrow on figure 3 shows. Three areas are defined: Productivity growth lower than 200 percent, between 200 and 400 percent, and larger than 400 percent.

Figure 3 shows that production growth and employment growth in the high growth sectors is lower in Sweden than among OECD member countries as a whole. The only exception is Drugs and Medicines (ISIC 3522) where, in particular, production growth is much higher for Sweden than for the OECD as a whole. Productivity growth of the high growth sectors is considerably higher in Sweden than in the OECD in four of the sectors (ISIC 3522, 3832, 3839 and 3845). For Drugs and Medicines (ISIC 3522) it is

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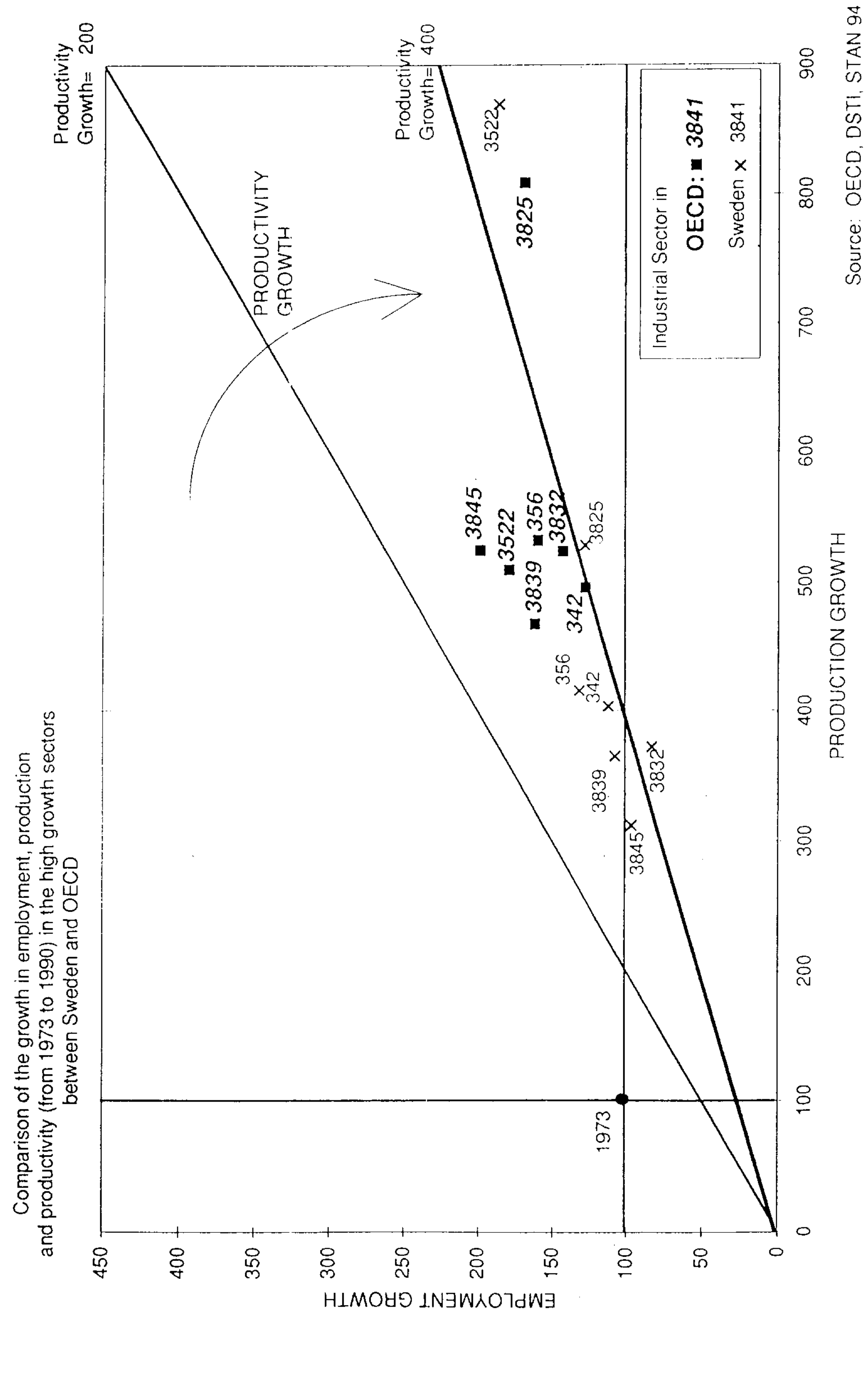
23 It is interesting to note that employment in the *non*-growth industry actually increased for the OECD as a whole during 1975-78. For Sweden there was a slight increase in this part of industry during 1984-88.

24 In the next breath it is often said that the employment problem must be solved by the service sector.

Figure 3. Comparison of the Growth in Employment, Production and Productivity (from 1973 to 1990) in the High Growth Sectors Between Sweden and OECD



much higher. It is slightly lower in Sweden than in the OECD in the three remaining sectors (ISIC 342, 356 and 3825).

If employment in Swedish industry had grown by the same extent as in the OECD (50 percent) in the growth industries during the 1975-91 period, then about

315 000 jobs would have existed in Sweden (in the growth industries) in 1991. This is 125 000 more than the actual figure.[25] This should be related to the fact that there were about 870 000 people employed in Swedish industry in 1991.[26]

Although profits were very high in the so called "basic" industries in Sweden during 1994-95, this is not true in a longer time perspective. In a twenty year perspective firms in the forest-based industries, steel, and mining are at the bottom of the "profitability league". This is in spite of repeated devaluations, which momentarily burst the profitability of the basic industries, thanks to their low imports and high exports.

The long term profitability of some firms in the basic industries (SCA, Stora, SAAB, Trelleborg, Modo, and Avesta) can be compared to advanced service firms like WM-data and Hennes and high tech ones like Astra. In the second group of firms profitability has been between 25 and 40 percent during the last twenty years. Also in somewhat more mature industries profits were reasonably high. Examples are Perstorp, Atlas Copco and Sandvik with a profitability of between 15 and 20 percent. These firms have started in the basic industries, but successfully advanced into more profitable areas. SKF on the other hand has a very low profitability. In the basic industry firms, profitability is only between 7 and 11 percent (Affärsvärlden 1995: 8-9). [27] In other words, the profitability in the traditional industries were considerably lower than in advanced service and high tech companies in a long time perspective. [28]

Within regular intervals, Swedish firms in forest, steel, and mining end up in deep profitability crises. These have often been "solved" through lowering the value of the Swedish crown.[29] Then profits soar. After some time, when profits have accumulated, the firms begin to invest - in their old product lines, both in Sweden and through direct investment in other countries. For example, currently (1995-96) the lion's share of investments are in the forest-based industries, the steel industry, and the transportation

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[25] If we had comparable data until 1995, this difference would probably have been even higher.

[26] It must be noted that the major crisis of Swedish industry in the early 1990's is only partly captured by the data presented. Between 1989 and early 1993 industrial production fell by 17 percent, with is more than during the depression in the 1930's, and 220 000 industrial jobs disappeared.

[27] Profitability is here calculated as average profits as a percentage of the company's own capital during 1974-1994. If measured in relation to capital employed, the profitability figures would be lower.

[28] The statements here are based only on scattered information. The profitability of industry in various sectors is the object in an ongoing research project, which will be reported later during 1996.

[29] The Swedish crown was devaluated four times during the 1976-82 period. In 1992 the crown was under strong pressure. The government and the Central Bank tried to defend it, but failed to do so. Thereby the crown collapsed and its value fell by 25-40 percent against important currencies. From the summer 1995, the value of the crown has started to increase somewhat.

sector (mainly automobiles), (SCB 1994 and Johansson 1996: 26). This further reinforces Sweden's dependence on the basic industries. Future demands for further decreasing the value of the Swedish crown therefore also increase.

The above means that Swedish industry has not exploited the possibility of creating more than 125 000 real jobs which would probably have been in highly profitable industries to a large extent, as well as being highly productive and fairly well paid.

But isn't it in the service industries that jobs are supposed to be created in the future? Yes, this is true in the long run. In the short and medium term, however, industry and industrial employment must also grow. The reason is that the share of industry in Swedish GDP is very low. In 1992 it was 18 percent. Out of 24 OECD countries, 16 had a higher figure. In Germany industrial production accounted for 29 percent of GDP, i.e., it was 61 percent higher than in Sweden (OECD 1995: annex table 1.5). In the current situation Sweden needs reindustrialization!

In addition, we know that each industrial job creates a number of jobs - perhaps three or four - in transport, telecommunications, computer services, trade, cleaning and building maintenance, and other service sectors. This means that the 125 000 jobs could have been half a million. It might be noted that this does not assume that Swedish industrial growth in the high growth sectors would outperform other OECD countries. It just assumes an average rate of growth, i.e., a lower one than for the leading countries.

The reindustrialization needed should to a considerable extent occur in the growth industries, which are, to a large extent, the same as the R&D intensive industries. It is certainly correct that industry alone cannot solve the unemployment problem and that it accounts only for less than one fifth of all employment. But there are important relations between various sectors of the economy. Therefore it is essential that the industrial fifth of the economy is dynamic and in good shape.

The overall conclusion is that Sweden's industry has not been renewed to the same degree as other OECD countries. New and rapidly growing technology-based firms have not emerged in the growth sectors (as in the USA). And the old, large firms have not diversified into new product areas (like in East Asia). Two important explanations for this are the regular devaluations and the inherent propensity of firms to stick to their traditional core business. A conserving industrial policy has also contributed - for example support to old industries in crisis ("akutmottagningen"), including support to the shipyard industry, in the 1970's and early 1980's.

For a firm there are always risks and costs associated with "changing track" and investing in the production of new products. Since the value of the crown has decreased from the mid-1970's on, the profits of firms in traditional industries have occasionally soared. This has made these firms reluctant to take "unnecessary" risks through diversification. After the depreciation of the crown in 1992, it therefore became "natural" that the lion's share of investments made by exports companies be in the traditional industries. Accordingly, the current large profits made by the export companies are not used for future oriented structural change. This is as true now as it has been in similar situations in the past, e.g., after the 1982 devaluation.

In the debate on growth issues in Sweden and elsewhere there is much argument that the labour market is rigid and therefore not efficient. One of the main implications of the above is, however, that the *capital market* does not seem to function efficiently. Profits are not, to a sufficient extent, transferred for investment from low profit sectors to high profit industries. They are locked into the low profitability, basic industries.

With a more efficient capital market, some of the profits would be transferred to and invested in the growth industries in Sweden, perhaps as an alternative to direct investments abroad in the traditional sectors. Such a structural change would not hurt the basic industries.[30] At the same time, it would mean a renewal of Swedish industry, a larger growth potential and increased employment.[31]

State intervention is only called for if a *problem* can be identified, i.e., something not automatically solved by market forces and private firms - and which the government has the potential of mitigating. Policy must not duplicate markets, but should complement them! In the design of a growth policy such "problems" must be identified.

That Swedish industry has failed to create the 125 000 industrial jobs in the growth sectors is certainly a *problem*, but it can also be seen as a *possibility*. It constitutes a potential for increasing industrial employment. These are the kinds of combinations that must be identified and focused in designing a Swedish "growth policy".

It must be emphasized, however, that the products labelled "growth products" in this paper are not necessarily the growth products of the future. To understand whether a set of growth products are "stable" or not, and therefore whether there is a strong correlation between "historical" growth sectors and "future" ones, we might calculate empirically what the growth products were during, for example, 1980-91 and 1985-91. This could serve as a basis for speculating about what would be the future growth products.[32] Products and sectors not yet heard of will, of course, also emerge. It would also be interesting to find out in detail what methodology the Japanese used in trying to identify future growth industries and products as a basis for formulating their long term innovation policy, which proved to be so successful.[33] Further, it would be important to evaluate the experience other countries have had in using "technological forecasting" to identify future growth industries.

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30 It is, of course, crucial that the Swedish natural resources and traditional competencies continue to be exploited.

31 On the average, capital intensity is lower in the growth industries than in the basic industries.

32 An analysis of the years after 1991 would, of course, also be extremely valuable in such a discussion! However, there is, for the time being, a lack of internationally comparable data.

33 The main general criteria for the Japanese seem to have been two. Firstly that the income elasticity of demand in the world as a whole should be high, and secondly that the comparative technical progress should be high for the products selected (Edquist 1994: 72).

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Appendix 1: Content of High Growth Sectors

Source: International Standard Industrial Classification of all Economic Activities, Statistical Papers, series M, no 4, rev. 2 , United Nations, 1968.

342-Printing & Publishing

Printing, lithographing, and publishing newspapers, periodicals, books, maps, atlases, sheet music, and directories; commercial or job printing of cards, envelopes, and stationery; manufacture of loose-leaf devices and library binders; bookbinding; blank book making; paper ruling; and other work related to book binding such as book or paper bronzing, gilding and edging; map and sample mounting; services for printing trades such as type-setting, engraving and etching steel and copper plates; making woodcuts; photoengraving; electrotyping and stereotyping. Type foundries are classified in group 3819 (Manufacture of metal products except machinery and equipment nec). Engraving on precious metals is classified in group 3901 (Manufacture of jewellery and related articles).

356-Plastic Products, nec

The moulding, extruding and fabricating of plastic articles not elsewhere classified such as plastic dinnerware; tableware and kitchenware; plastic mats; synthetic sausage casing; plastic containers and cups; laminated sheets, rods and tubes from purchased plastic raw material; plastic components for insulation; plastic footwear; plastic furniture; and plastic industrial supplies, e.g., machinery parts, bottles, tubes, and cabinets. The manufacture of plastic house furnishings such as curtains or tables covers, is classified in group 3212 (manufacture of ready-made textile goods except wearing apparel); the assembly of plastic toys and dolls, athletic and sporting goods is included in group 3909 (manufacturing industries, nec) and the manufacture of plastic luggage, hand bags, pocket books, and similar goods is classified in group 3233 (manufacture of products of leather and leather substitutes).

3522-Drugs & Medicine

The manufacture, fabrication, and processing of drugs and medicines, including biological products such as bacterial and virus vaccines, serums and plasmas; medicinal chemicals and botanical products such as antibiotics, quinine, strychnine, sulpha drugs, opium and derivatives, adrenaline, caffeine, codeine derivatives, and vitamins; and pharmaceutical preparations for human or veterinary use.

3825-Office & Computing Machinery

The manufacture, renovation, and repair of office machines and equipment such as calculating machines, adding machines, accounting machines; punching card system machines and equipment; digital and analogue computers and associated electronic data processing equipment and accessories; cash registers; typewriters; weighing machines except scientific apparatus for laboratories; duplicating machines except photocopying machines; and other office machines.

3832-Radio, TV, & Communication Equipment

The manufacture of radio and television receiving sets, sound reproducing, and recording equipment, including public address system dictating machines, and tape recorders; wire and wireless telephone and telegraph equipment; radio and television transmitting, signalling, and detection equipment and apparatus; radar equipment and installations; parts and supplies specially used for electronic apparatus classified in this group; semi-conductor and related sensitive semi-conductor devices; fixed and variable electronic capacitors and condensers; radiographic, fluoroscopic, and other X-ray apparatus and tubes.

3839-Electrical Apparatus, nec

The manufacture of other electrical apparatus, accessories, and supplies not elsewhere classified such as insulated wires and cables; storage and primary batteries, wet and dry; electric lamps and tubes; fixtures, lamp sockets, and receptacles; snap switches, conductor connectors, and other current-carrying wiring devices; conduits and fittings; electrical insulators and insulation materials except porcelain and glass insulators, which are classified in group 361-Pottery, China, etc., and 362-Glass & Products, respectively.

3845-Aircraft

The manufacture, assembly, re-building, alteration and repair of aeroplanes; gliders, aircraft parts such as engines, propellers, pontoons, and under-carriages; space vehicles, and hovercrafts and specialized parts. The manufacture of aeronautical equipment is classified as international in the appropriate section of major group 383 (manufacture of electrical machinery, apparatus, appliances, and supplies); the production of aeronautical measuring instruments is classified in group 3851 (manufacture of professional and scientific equipment and measuring and controlling instruments); the fabrication and assembly of missiles and rockets is classified in group 3829 (manufacture of machinery and equipment except electrical, not elsewhere classified).

THE ROLE OF NEW TECHNOLOGIES IN FINLAND

Tarmo Lemola*

Introduction

I have formulated the subject of my paper together with the conference organizers, and take full responsibility for it. However, I would like to say that the more I thought about the topic, the more problematic it seemed to be. The problem is not what is meant by new technology, because we can always reach agreement on that. In recent years it has usually meant three things - information technology, materials technology and biotechnology - plus sub-areas within each of these.

For me, a more problematic aspect is the fact that the title includes a typical effort to pose questions for future research. The new technologies should be identified and their relationship to economic and social developments defined. On this basis the future development of technologies would be analyzed, the opportunities and threats inherent in the options identified, and recommendations proposed for action through which threats could be repelled and opportunities exploited.

While I place great value on this kind of scenario-building, my own basic orientation is different. With respect to industrial change, consideration of the roles of individual technologies is not necessarily very fruitful. Technological change is a technology specific, but still more a context specific phenomenon. With this in mind, I will concentrate in my paper on how the structure of Finnish industry has evolved in recent years and on its developmental needs. What we have here is a process of continuous renewal in which the existing technologies themselves, new versions of them, and entirely new technologies are all needed. We should keep in mind that reliance on existing technologies and structures is vital for the renewal of technologies and industrial structures. This may sound like a constraint, but there is equal justification for considering it both a necessity and an opportunity.

The Need for Structural Change in Finnish Industry

"Foreign trade is no longer a matter of exporting products containing cheap raw material (we have lots of forests) or cheap labor or capital. Trade is to a large extent based on specializing on something that you do well and acquiring a worldwide market for it."

* VTT, Technical Research Centre of Finland, Group for Technology Studies.

This is how Sirkka Hämäläinen, chairman of the Board of Management of the Bank of Finland, expressed it in an interview in the newspaper *Helsingin Sanomat* of August 26, 1995. There is really nothing to add except that Sirkka Hämäläinen is neither the only nor the first person to recognize the essential contribution of specialization and know-how to industrial and economic success. The same arguments were much to the fore in discussion of structural policy in Finland in the 1960s and 1970s and economic historians can cite many statements of similar content from a much earlier time.

In fact, it would seem that Finland has almost always been "in a period of significant industrial change" for which specialization based on know-how has been offered as the principal solution or means of adjustment. A recent example is the "National industrial strategy" (Ministry of Trade and Industry 1993) published in 1993. According to this report, the current changes and subsequent adjustments made by industry are primarily related to the opening up and internationalization of the economy. The operating environment of industry is also changing rapidly. Priority in competition has shifted to the market for factors of production; national economies are beginning to compete for companies and for skilled labor. With respect to productive activity, those areas which offer an efficient infrastructure, skilled labor and an advanced technological structure will become attractive. This is the core of the new business policy that is summarized in the report.

The ETLA publication entitled "National competitiveness and the industrial future" (Hernesniemi, Lammi and Ylä-Anttila 1995) takes the same approach. The book looks at the competitiveness and future growth prospects of the Finnish industry on the basis of Michael E. Porter's theory of the competitive advantage of nations. Finland's industrial clusters, of which the forest sector is the strongest, have often evolved out of factors of production, although their strongest competitive advantages are nowadays found in know-how. The relative advantage of Finnish industry is in fact shifting gradually from capital- and raw-material- intensive sectors to know-how-intensive areas. Telecommunications is the most rapidly growing of the new clusters. It is now in the formative phase, although it is backed up by several strength factors such as technical innovation that make the potential of the 'tele' cluster credible. Know-how is the key factor for this cluster.

In its own report, "The Global Economy and Finland," VATT operates with slightly different concepts from ETLA, although it also stresses specialization based on know-how (the Government Institute for Economic Research 1995). VATT emphasizes that successful growth in the developed countries depends increasingly on their ability to stay in the forefront of technological change. Innovation, that is the creation of new products and the renewal of production methods, is vital for firms in both traditional export sectors and the domestic market. The emphasis in corporate innovative activity is reflected in a general need throughout society to increase the national 'knowledge' stock, which creates the basis for success.

"The New Industrial Finland" (1995) by Eloranta, Ranta, Ollus and Suvanto departs in style from the others. It is more provocative, although the conclusions and recommendations conform to the general line, which could already be termed a consensus line. According to the book, the core of Finland's competitive efficiency should comprise know-how, education, new technical solutions and the ability to renew and develop continuously. However, the problem in Finland is that a few areas of strong competence - the forest industry and the related equipment industry - are not able to support the entire country.

The basic premise of Eloranta et al. is that continuous development and globalization of traditional sectors must be secured. This will require development of new operating procedures and also the creation of new strengths. The writers believe that new opportunities will be found above all in high technology, especially electronics and electrical products. They consider developments of recent years in these sectors an encouraging example of the opportunities afforded by structural change and of what systematic input in knowledge and know-how through education and research can accomplish.

The basic elements of Finland's industrial strategy can be condensed as follows on the basis of what was said above:

- A strategic core of specialization based on know-how.
- Continuous development and globalization of traditional sectors.
- New opportunities to be found in high technology, particularly in the 'tele' cluster.

One could imagine that the development of knowledge and know-how in Finland in recent years would have been the object of particular activity in the public sector. This, however, has not been the case. The gap between rhetoric and action has actually widened rather than narrowed. As far as improvement of research and technical training is concerned, we have been standing still or have even lost ground. In Finland we have hidden behind the need to cut back governmental expenditure and perhaps also relied increasingly on the "invisible hand" of the market economy.

High Technology as the Growth Sector

An important common denominator in discussion of recent years has been the strong belief that high technology is the sector that will put Finnish exports on a growth track. There are strong grounds for such optimism. On the whole, Finnish exports have done very well in the last few years, and high tech in particular. Exports of these products totaled FIM 11.0 billion in 1990, which was 10.8% of total exports (Statistics Finland 1992). In 1994, the value of high-tech exports was FIM 23.9 billion, accounting for 15.5% of the total (Statistics Finland 1995). Apart from growth, Finns have been pleased with the fact that Finland has pulled ahead of Sweden, where the figure for high tech was 13.5%.

There are at least three considerations that have not received the weight they deserve in discussion concerning high technology in Finland. The first of these concerns the relevance of high technology and its classification in general. The second is the relative concentration on specific product groups and companies within the high tech sector.

The third issue closely related to the above is the key role played by Nokia in the central high-tech product group, that is in telecommunications equipment.

Problems in classification

There is reason to ask what sense it makes to classify product groups as 'high tech.' Does the information produced by this classification make our knowledge of Finland's production structure and competitiveness more profound or is it actually leading us astray? I am personally inclined toward the latter position; I am also inclined to recommend that the high-tech concept be used more sparingly.

In principle, the criteria and goals for identifying high-tech products are easy to understand and accept. The goal has been to bring out those products, processes or production sectors which

- have a strong dependence on research and development
- have strategic significance for governments
- are characterized by rapid obsolescence
- call for extensive outlays of risk capital, and
- require strong international co-operation and competition.

In practice, this configuration has undergone significant simplification. Available lists of high-tech products are based almost entirely on the research-intensiveness of industrial sectors or in recent years of product groups. In other words, we have a category comprising a variable based on a single property. Reality can be streamlined, but not oversimplified.

The OECD played a crucial role in the proliferation of enthusiasm for high technology. In the early 1980s it divided sectors into three groups. Those sectors in which research costs accounted for more than 4% of the value of production were classified as high tech, those where the figure was 1-4% as medium tech and those with a figure under 1% as low tech. The research-intensiveness of various fields was computed from information for 1970-1980 as an average weighted with the size of the 11 largest OECD countries. The conclusion reached with these criteria was that high tech is in fact identical with the electrical, electronic and part of the chemical industries.

Acquisition of data concerning exports and imports of high technology has required conversion of data based on industrial production to that used in foreign trade statistics. The latest information is based on version 3 of the SITC classification, although data based on the former version are still extant. There are also country applications, and EUROSTAT has had its own version of the high tech product groups. Overall, the statistical base has been varied.

In Finland, analyses based on the OECD classification have been made since the mid-1980s (Lovio 1985, Statistics Finland 1987 and 1990). At the outset, the results aroused curiosity, but also confusion and even outright indignation. In Finland we were especially disturbed by the fact that not only our paper products, which include a high standard of know-how, but also the top products of our engineering sector related to the forest industry such as paper machines were also relegated to the bottom of the list. We took a slightly more positive attitude in the early 1990s when we observed that our high-tech production and export figures were among the few bright spots in the otherwise gloomy state of our economic and industrial development.

The present high-tech classifications are based mainly on the following assumptions: research-intensiveness depicts the growth and development potential of the product group; the average for the largest OECD countries is directly applicable to all countries; no major changes will occur in the research- intensiveness of the product groups.

All these basic assumptions must be questioned. Dependence may exist between the research-intensiveness of the product group and its potential for development, but many factors other than the extent of research and development expenditure, for example the indirect inputs of technology used by the product group, also affect the potential (Virtaharju and Leppälahti 1993, Vuori 1995). The OECD averages for the largest countries do not permit taking the background and special developmental features of the production structure of different countries, and especially of the smaller ones, into account. Moreover, the research-intensiveness of the product groups is changing constantly.

In Finland, too, there has been some support for a purely national application of the high-tech classification. There are no grounds for this, particularly if the principal motive is to raise the percentages for high tech exports above the current level. In contrast, there might be justification for gradually reducing the excessive attention focused on high-tech export figures and for seriously considering what our nationally critical and strategic technologies really are, for making the relevant international comparisons, and for planning the actions needed to keep these technologies and the companies developing and using them on the leading edge.

Concentration of high-tech exports

If we nevertheless put the concerns mentioned above aside and look at the figures of exports in high tech as they are, the first observation is that exports of high tech are still a rare delicacy in Finland. The major product groups are telecommunications equipment, automatic data processing equipment, electric generators and motors, and electrical transformers and rectifiers. In 1994 these accounted for 74%, as table 1 below indicates, and they have significantly increased their share in the 1990s. The largest export product group in the high-tech sector comprises telecommunications equipment, which includes telephone, telegraph, radio and TV equipment. Its share has risen from 21% in 1990 to 39% in 1994.

	1990 %	1991 %	1992 %	1993 %	1994 %
Telecommunications equipment	21	33	25	32	39
Automatic data processing equipment	8	11	16	17	16
Electric generators and motors	6	7	8	13	11
Electrical transformers and rectifiers	7	8	7	8	8
TOTAL OF ABOVE GROUPS	42	59	56	70	74
TOTAL EXPORT OF HIGH TECH (FIM, current prices)	11,0	10,1	13,5	18,4	23,9

Table 1. Finland's major high-tech product groups in 1990-1994

You need only manipulate reality a little bit, if at all, to make the product group data company-specific. The top three exporters of high-tech products in 1994 were simply the following: Nokia, ICL and ABB, three large companies, two obviously foreign-owned and one almost as obviously. Fortunately for us, these companies have decided to stay in Finland for the time being; even more gratifying is the fact that all three have actively developed their own operations here.

However, the above indicates that in its high technology, Finland is strongly dependent on the actions of the few largest companies and on whatever success they achieve. Furthermore, it would also seem that this dependence is increasing rather than decreasing. The figures for 1993 and 1994 primarily reflect the success of Nokia in the rapidly expanding global telecommunications market. Data for the current year suggest that Nokia's growth rate will even accelerate. This means that the contribution of the product group represented by Nokia, that is telecommunications, will continue to expand.

These developments do not entirely conform to expectations and hopes. We would prefer to have a large group of new and dynamic SMEs responsible for development instead of a few large, established enterprises. One of the most frequent buzzwords in debate on industrial policy in Finland during the last few years has been 'reindustrialization' (Office of the Council of State 1992). This has meant expanding the open sector rapidly by setting up new companies. The official rhetoric has repeated the firm conviction that high technology is the most fruitful growth sector for new companies.

The 'invisibility' of small, innovative companies may have three causes. One is that there are not any. Another is that they are only now emerging, and the third is that they do in fact exist, but our statistics do not reveal them and the media tend to ignore them. Since there are not reliable studies on this vital subject, we have to make assumptions.

My assumption is that the minor role played by small companies is the sum of all three causes. The best thing is that in Finland, the telecommunications sector in particular is also providing encouraging examples of the second point, that is of the emergence of small, innovative companies. But before we go into this subject, a brief account of Nokia's position in this sector is in order.

Nokia: One Above the Others

Nokia does not reflect the randomness of a shooting star. Its key components, the forest, rubber and cable industries, were concentrated in a single owner back in the 1920s. Its modern 'conglomerate' form dates back to 1966. It has become accustomed to financial soundness over its long history.

It began development of an electronics industry in the 1960s. Thanks to its own product development, but even more to some fortunate and less fortunate company acquisitions, Nokia gradually evolved into a telecommunications and electronics company. At present, 70% of the company's operations are related to telecommunications.

At the beginning of the 1990s Nokia confronted a crisis. It would seem that its existence as an independent and united telecommunications and electronics company was in more than considerable doubt. It sold, or was forced to sell, its computer industry to the Japanese ICL in 1991. It was left with mobile phones, telecommunications systems (that is telephone networks), and home electronics. By actively developing these sectors, separately and together, Nokia has managed to embark on a growth track in a few short years. A similar record is difficult to find in Finnish economic history.

Nokia has nearly 32,000 employees, which obviously makes it a major company. It is not even necessary to produce exact information about Nokia's share of the production, employment, exports and imports in Finland of its main sector, telecommunications, to demonstrate its size. We are otherwise aware that Nokia is responsible for most of it. Without Nokia, the map of the Finnish telecommunications industry would look quite different than it does today.

Also, innovation in the telecommunications sector in Finland is highly dependent on Nokia. If for lack of a better indicator of innovative activity we use patent applications for the telecommunications sector submitted in Finland during the 1990s, we can make the rough generalization that Nokia is also responsible for most of them (Lievonen 1996). Moreover, its relative importance has steadily increased, as table 2 shows. The figures give reason to applaud Nokia's success, although also to ask whether Finland is not increasingly dependent on a single card.

	1990 %	1991 %	1992 %	1993 %	1994 %
Nokia	71	73	78	75	77
Oy LM Ericsson Ab	8	6	1		1
Other	21	21	21	25	23
Total	100	100	100	100	100
Number of patent applications	100	139	167	207	274

Table 2. Patent applications submitted by the telecommunications sector in Finland, 1990-1994 (Lievonen 1996)

From the national point of view, the significance of Nokia in technological development is three-fold. First, its core is in the **hierarchy** built into the organization. This is the basic form of governing the company's research and development. Secondly, Nokia also operates in the **market** by acquiring new products and services from other companies and organizations. Thirdly, it is involved more informally in various national and international **networks** together with other companies, universities and research institutes. No-one outside Nokia really has a clear conception of the whole, scarcely even the key people in the company themselves.

By its own reckoning, Nokia employs one person outside the company for every employee of its own through its subcontractors (Helsingin Sanomat, October 3, 1995). According to the same source, the telecommunications group has around 500 subcontractors, half of which are abroad. Nokia does not make any of its own semiconductors, components for mobile-telephone circuit boards or plastic cases. Some of the subcontractors also supply components to Nokia's competitors. For its part, Nokia manages the delicate relationship with subcontractors by retaining at least two for each component.

It is really annoying that we know so little about the position and role of the subcontracting network of our communications sector in Finland. However, we can imagine that apart from Nokia, the future of the entire sector depends in the long-term on how this undergrowth, which is flourishing at the moment, will manage to expand, evolve and become independent. Raimo Lovio has written and interesting and thoughtful account of the circulation of corporate structures (Lovio 1989 and 1994). Small innovative companies are significant, but they usually evolve out of large, existing organizations or from around their fringes. However, in order to succeed and grow they also return to their parent organizations. We should have a better grasp of these processes and dynamics.

I would elevate learning to recognize a positive circulation and being able to encourage it at the right time and in the right way into a major challenge for industrial and technology policy. The first challenge would be to explain openly whether we really need government intervention, or would we do better without it. In Finland, we turn quite too readily to government intervention in the form of money or services when we need something done. Aid does not always cause direct harm, except when no-one benefits from it. A second challenge is to pinpoint the potential nodal points of the network, not the holes, and to strengthen them so that the systemic nature of technological change and the needs and opportunities of various actors can be taken into account (Lemola 1995).

Conclusion

Finland does not need new technologies as such. It does need to improve its present production structure so that the national product will grow at a reasonable rate and people will have jobs, particularly of the kind that are interesting and give satisfaction. We assume that such work requires knowledge and know-how. In other words, we would like to be educated and to do the kind of work that suits educated people. This goal is a good one and entirely understandable.

The cornerstones of Finland's industrial structure have traditionally been (i) the further development of an existing product or process, (ii) improvement of the quality of products by combining new technology with existing products and production processes and (iii) establishment of new corporate activity in advanced areas of technology. Moreover, a division of labor in which large companies would be responsible for the first point has been conceived. New, innovative companies would be needed to implement the third point. Large companies are not excluded from producing innovations, but a great deal has been built on the assumption that they will come from other quarters.

In this paper I have sought to emphasize that we are apparently much more dependent on the existing production structure and large, established companies in the creation of new products and processes than we would like to admit. A significant part of renewal comprises the slow restructuring of companies. There is really only a problem in the event that we close our eyes to reality and in our enthusiasm construct support structures that can never be realized.

This does not mean that large companies can achieve whatever they set out to do. There is a good example of this in the Finnish biotechnology sector. In anticipation of future growth, many food, forest and pharmaceutical companies invested heavily in biotechnology during the 1980s. The results were more modest than expected. The same goes for the new small businesses that were established in the sector. The real new biotechnical companies are still few in number in Finland, nor are there any true success stories in this sector (Halme 1994).

Neither is there any reason to deny that there are also problems and risks involved in big companies and their networks. They have their own established interests, which they cling to both tightly and selfishly as well. They are inclined to resist change and reform or to take an indifferent attitude when such efforts are not in complete harmony with direct corporate interests. One might even say that support for innovative activity in these companies actually amounts to support for the further development of activities that are already established. One could imagine that the problems of this kind in the communications sector controlled by Nokia are few, but if a problem is possible in theory it is usually feasible in practice as well.

With respect to technology policy, the situation is difficult. In Finland, too, it is quite obviously to be seen that the scope available to technology policy is narrowing. There is general agreement that large, established enterprises must not be the primary objects of governmental technology policy. If it also shows that the prospects for the emergence of small companies are smaller than expected, then the options of govenrment intervention in the form of technology policy are few, or at least fewer than in the near past.

Eloranta, Ranta, Ollus and Suvanto would also seem to believe firmly that new industrial activity will evolve largely through the internal renew of existing companies. They speak of a change in corporate operating procedures. Less attention is focused in the book on the quantity and quality of government intervention. The authors state that a top-down assessment in the development of existing strengths, that is an assessment of critical and key technologies ("emerging new technologies") is also in order. Unfortunately, no further progress on this issue is forthcoming.

To conclude, I would like to focus attention on the following points of view:

- The size and age of a company should not be overestimated in considering the need for public research and development and channeling of resources. Technology is developed in essentially the same way, whether the companies are large or small. Most important is, that we avoid any support for efforts that firms will in any case undertake on their own.
- Careful consideration should be given to finding forms of governmental intervention that could provide positive support to the development of technology taking place in the interfaces between large and small companies. If we use the three forms of governance, hierarchy, market and network, then Finnish technology policy has operated mainly in the realm of the first and third. Would there be reason to promote market-based research co-operation and could the means for such efforts be found?
- Finland has in recent years overstressed the idea that in a university or research institute, only research and development that serves the immediate needs of companies are justified. We should understand that only basic competence, both extensive and in-depth, will create sufficient capacity for the development of successful products in the following decade. Achievement of this goal will require institutional changes.

- Technology policy in Finland, too, has been extremely expert-centered. For example in the development of multimedia, a truly national program could be developed for Finland. For the first time in the history of Finnish technology policy we might a unique opportunity to widen the traditional scope so that users and consumers would not be merely objects, but subjects of technology policy as well.

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INTERACTION BETWEEN THE CORPORATE AND THE PUBLIC SECTORS IN GLOBALIZATION

Seppo Leppänen*

The division of labour between private and public sector in internationally integrated economies is clear: private entrepreneurship is the driving force to growth and public sector should supply a healthy infrastructure - stable macro environment and incentives for flexible micro economic behaviour. The interdependence between the two sectors has got a new light because of the framework given by rapidly developing endogenous growth theory. Also the public sector consolidation problems and reassessment of welfare societies have given a new perspective to the private-public sector interaction.

My presentation is based mainly on a book "Global economy and Finland"[1]. The book was a synthesis for the issue. First I would like to describe the report framework. Then growth policy of a small economy in a globalized world will be touched upon. I will refer to some Finnish examples in this interaction process and lastly I will deal with risks and limitations in globalization of a small economy.

Framework

For a long time main stream economist's theoretical thinking on growth was very limited when it came to advising governments on how to promote growth. The traditional neo-classical growth theory assumed that economic growth is a result of labour and capital accumulation. Population growth and savings would determine long-run growth. The unexplained residual was thought to be exogenous technological progress. This leaves the role of the public sector almost outside the theory. The usual prescriptions for growth - more saving and schooling - left much to be desired.

The endogenous growth theory, which has been under intensive development and discussion among economists and policy makers during the last ten years, will provide a better framework for the assessment of public sector in growth promotion. The basic idea behind endogenous growth theory is the promotion of profit motivated innovation and knowledge spillovers. If innovation is endogenous, then there must be elements in the public policy that promote or hinder the creation of new knowledge. If knowledge spills over to the other agents in economy, the scope of intervention in the knowledge creation and diffusion sector becomes larger than advised by simple efficiency

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[1] Eds. Seppo Leppänen and Antti Romppanen: Government Institute for Economic Research, Helsinki, 1995.

calculations. Introduction of spillover externalities and human capital also means that returns to investment are not necessarily diminishing and thus growth rates between developed and less developed countries do not have to converge (Romer, 1994).

In the globalization context the starting points in endogenous growth theory can be summarised by stating that
- innovation is a major source of growth
- competition is a major source of innovations and
- international trade is a major source of competition.

Economy's historically accumulated human capital is an essential precondition for innovation. Investments in human capital are mainly subsidised by the public sector especially in European economies. High quality human capital and other knowledge infrastructure and a good telecommunication network are prerequisites for the diffusion of innovation and new technology.

Innovative activity entails also large fixed costs and big risks. Thus utilisation of large global markets is needed. Successful innovative activity typically provides the entrepreneur with a monopoly position in the market for a certain period of time. A successful innovation will normally lead to a monopoly situation sometimes for an innovator when supplying a new product or winning market shares by applying a process innovation.

A question can be raised: why and how will the government share the risk connected to innovation? One answer is that the government should subsidise innovation because of the positive spillovers of innovative activity.

One issue which I would like to point out is that in a modern high-tech activity the life cycle of the product has become shorter and the product is seen as a process. The product is tailored according to the needs of the market, the information of which is combined by marketing experts. The product is a result of a combined process of innovation, production and marketing, the financing connecting to all part of that process. In these kinds of interconnected processes, which geographically might happen in many countries, also the international agreements negotiated by the government are essential elements.

All in all innovations which are prerequisite for success need a good knowledge infrastructure and communication network, and the possibility to gain a monopoly position for a certain period of time. The government interventions and measures are connected to most phases of this process and they are justified because positive spillovers are connected to these measures.

Growth policy in global economy: basic premises

- Free international trade. Vital interests are also secured by strategic agreements.
- Stable and credible macro policy is compatible with the low real interest rate, which in turn are prerequisites for capacity increasing and renewing investments.
- Public sector expenditure should be focused on education, basic health care research and development which improves the knowledge infrastructure of the society.
- Create incentives in taxation, income transfers and public services to enhance savings, risk taking and entrepreneurship in the economy.
- Better functioning and more flexible labour market in order to maintain price competitiveness.
- Investments in infrastructure, especially in transportation and telecommunication networks to ensure competitiveness.

Growth Policy of a Small Economy in a Globalized Environment

Positive spillovers connected to human capital investments and R&D activity mean that the government has a leading role in supplying a good knowledge infrastructure for corporations. Also stable and credible macro-policy including a healthy monetary mechanism is a self-evident duty of the central government. A more controversial issue is whether the government should share directly the risks or control the monopoly tendencies connected with innovations.

The ideas of the new growth theory have been adapted widely by politicians. President Clinton's program included some aspects that are derived from the new growth theory, although the implementation has not proceeded as expected. The recently published European Union White Paper, OECD Jobs Study (1994) and World Bank's The East Asian Miracle (1993), report were based on the new growth thinking. However, endogenous growth theory also gives a powerful tool for special interest lobbying. The frontier between private and public activity in these areas is often very uncertain. These issues will be touched upon later on when discussing some Finnish examples.

Some Finnish Examples Concerning the Interaction Between Corporations and the Public Sector

The conclusions expressed above were very general. I would like to remind also that it is not possible to express any clear system or policy lines concerning these interaction issues, which are ultimately dependant on very pragmatic policy measures, where lobbying activity has substantial influence in political decision making. In the following I would like to characterise interaction between the corporate sector and the public sector by some practical examples.

(i) Traditionally the public educational system is considered to be rather rigid in changing its activity in front of new challenges characteristic of the demand-led global production system. A leading Finnish multinational company, Nokia corporation, was considering a decision 5-6 years ago: should the R&D centre of mobile telephone system be established in the United Kingdom or in the Helsinki region?

The company was worried about whether they will get enough qualified research staff in Finland compared to the UK. The company negotiated with the Ministry of Education and the Technological University of Helsinki on that issue. Nokia management realised that because their name and image during those days was not so good in the UK they might not be able to recruit first class researchers. On the other hand in Finland Nokia company would be able to receive the first class Finnish researchers if there are enough. The Finnish educational officials got the company convinced that the needed shift in educational programs is possible to carry out and Nokia constructed the research centre in Finland .

All in all the education in the rapidly growing branches is a problem. The changes in education system take time. The public educational system in many cases is not changed according to the rapidly changing needs of the corporate sector. So the corporations have to take a bigger responsibility for training and education.

The university system will furthermore be responsible of the basic research and the diffusion of new international knowledge to the private sector by different measures. The corporate-led research activity will not guarantee the creation of new, scientifically interesting knowledge. Therefore the qualified and competitive university and research centre system for which the public sector has the main responsibility is self-evident especially for a small economy.

The multinationals are forcing national states and regions to compete with each other for foreign direct investments. The strategic research centres are divided more and more between countries. The role of the public sector in this kind of network is rather problematic. For instance the Nokia corporation has in its mobile-telephone branch R&D centres in 4 countries and production units in 5 countries. They are working in an interactive network.

(ii) We had in our "Global economy and Finland" -project a special subreport by Torsti Loikkanen (1995): how the innovations developed in the Government Technological Research Centre (VTT) have been diffused to marketable new products and process innovations in the corporate sector. Altogether 150 innovations were in the sample.

The research activity of the VTT is divided to the state budget financed strategic basic research and commercial commission research demanded by the corporate sector. From the VTT the technological knowledge is diffused to the private sector e.g. by the spin-off companies, by recruitment of researchers, by patents and licenses and by the published research. There is quite intense interaction and communication network between VTT and the corporations in practice. The important role of VTT is to help the diffusion of international knowledge by adapting and tailoring it for the use of the firms situated in Finland.

(iii) One special and important feature in the "Global economy and Finland" project was the case of small and medium-sized firms in globalization process and their relations to the public sector. In Finland the small and medium-sized firms have a relatively smaller role in the economy compared to the other Western-European economies. In Finland the big company dominance is relatively somewhat higher than in the other small OECD-countries.

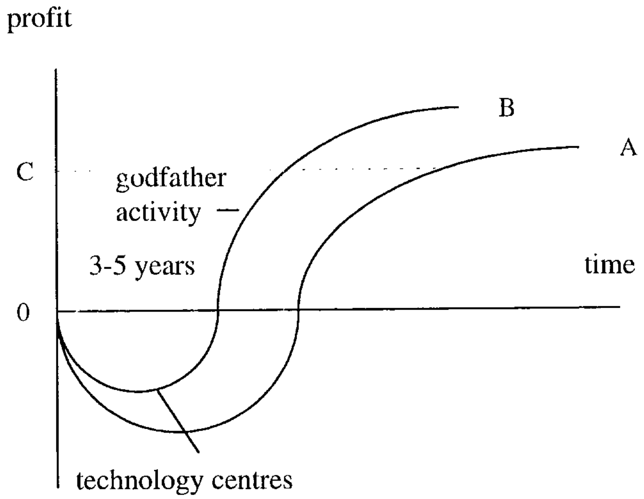
In the next five to ten years the small and medium-sized firms are important from the point of view employment and EU integration especially. New employment opportunities will be mostly in the SME sector. In considering the shorter life-span of products, tailor-made products according the needs of customers and the products seen as a process of innovation, production, marketing and risk financing, the SME are much more dependent on the central governments than the bigger companies, because risks of innovation and problems of international market penetration. The SMEs have an important role in the intraindustry trade in EU integration. In Finland the intraindustry trade is not very extensive.

We can raise the question: what is the safety network supplied by the central government for SMEs concerning the support of innovation, production, marketing and financing in globalization process? According the report by Torsti Loikkanen the SMEs are more dependent public sector support than the bigger firms. The results are consistent with that of international research.

(iv) The issue connected to the small and medium-sized firms globalization in Finland is so called "godfather" activity. The experienced corporate managers and experts have started to act as godfathers of the new high-tech SMEs almost without charge. The godfather is acting as a coach and adviser of the firm assisting the planning of export and advising to formulate. the foreign contracts. He will bring the credibility to the firm in negotiations and risk financing. This activity will be touched upon more in Yrjö Toivalas article.

The targets of the godfather activity could be described by the following chart. At the beginning of the firm's lifespan - during the R&D phase - the result of the firm is negative. When the production has started the firm is looking after markets and the results improve. In the R&D phase the firm will get support from the government technological centres connected with the universities. That will shorten the risky R&D development time. The godfathers come to the scene when the products are at the market and the turnover has started to grow. The target of the godfathers is to strengthen the growth period to reach the activity level C faster than otherwise. The curve A is describing the activity without the help of the technological centres and the godfathers.

Figure 1. The Development of the Profit of the Starting Firm



Some Risks and Limitations in Globalization

I would like to comment lastly briefly on some risks and limitations in globalization of a small economy.

(i) Firstly, there are some absolute size-limits of a high-tech firm or a part of the firm because of human capital shortage. The firm might need more specialized, qualified personal than a small country can supply. There are also difficulties in getting qualified personal from abroad because of high average and marginal tax rate and other obstacles. Tax harmonization has to be also considered from the point of view of keeping high-tech firms inside the territory of a country.

(ii) Secondly, for the diffusion of innovations and technology in a good communication network is necessity. That will need public money especially in a small economy where the private resources are more limited than in major economies. Also adult training and education is undersubsidised compared to that of young age cohorts. As public sector consolidation in most OECD countries is inevitable, the development of these infrastructures might be delayed. For the small and medium sized firms that is even more difficult because these firms are most dependant on public sector subsidization in their R&D activity, risk financing and marketing.

(iii) Thirdly, sometimes we can hear the argument: Why do we put taxpayers money for subsidising innovations because the fruits of innovations will spill abroad if for instance domestic multinationals are transferring their headquarters and the R&D units abroad. That is really a problem, but according to some comparative studies small countries will gain most from the R&D activity of the competitors.

(iv) Fourthly, the question which is also raised especially in a small economy is: should we focus our limited public and private resources to some special and narrow fields or is it necessary also for a small country to proceed along a wide front in education and innovation policy? We must remember that in intraindustry and intrafirm and intrascientific networks a quite wide front is needed when developing innovation in some special area. Innovations are often based on innovations developed in industries or sciences, which are sometimes rather far the from area of the original innovator. So the specialisation should not go too far.

(v) We saw in our Global project that in Finland there has been in globalization a later-comer problem. Firms went to foreign markets in Europe and Asia etc. after gloomy demand prospects in their traditional domestic and Soviet markets and in some cases after market shares were already secured by competitors. How could the domestic research or the network of embassies diminish or shorten that delay?

All in all the distribution of labour between public and private activity is an interesting question not only in reassessing of welfare society from the point of view of households´ well-being, but also in discussing of the interaction between the government and corporate sector.

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THE NATIONAL INNOVATION SYSTEM AND EMPLOYMENT

Erkki Ormala*

Introduction

This paper deals with the role of the national innovation system as a potential means of fighting unemployment in Finland. The importance of the national innovation policy measures is expressed in the government programme in 1995 as follows: "Halving the unemployment rate during the electoral period will call for a rapid economic growth and an industrial policy aimed at a knowledge intensive reindustrialization and at a well-developed small and medium-sized enterprise sector."

Finland is a small open economy whose development in the fields of economy as well as employment is closely related with international developments. For this paper, one starting point is provided by the general picture formed of the international developments by the extensive OECD studies and surveys of the mutual relationships of technology, productivity and employment. The OECD findings have, among other things, contained clear indications as to how Finland could make use of the various opportunities offered.

Another starting point for the paper is provided by the national research work bearing on the employment effects of the knowledgeintensive growth and the conditions on which these effects can be achieved.

In Finnish debate concerning the employment situation both of the above-mentioned starting points of this paper have received very limited attention so far. Thus the present paper is intended to supplement the various issues to be considered in planning the national employment policy in Finland. Main focus will be on the interrelationship between the innovation system and employment.

Innovation policy measures alone do not solve the Finnish unemployment problem. The innovation system and its development are nevertheless an integral part of the measures which, together, make it possible to attain the goal set by the Government: to halve the unemployment during the electoral period. Innovation policy measures will be of special significance for the attainment of our dual goal of curbing the unemployment rate while maintaining the vital characteristics of a Welfare State.

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International Findings

The following will be a twofold discussion, first, of the results of the international Jobs Study carried out by the OECD during the years 1992 to 1994, and secondly, of the intermediate findings of the follow-up study launched on that basis in 1994 on the initiative of the G7 countries. This OECD G7 Study will specifically focus the interrelationships between technology, productivity and employment. The results of the study will be published in summer 1996.

One central conclusion from international research is that the developments in the field of employment are essentially dependent on the individual economy's capacity to make its industrial structure more compatible with the opportunities offered by the international market and technological development. Within the OECD, new high-wage jobs are mainly created in the sectors of knowledge-intensive production and services. World economy is undergoing a rapid change towards a knowledge-intensive growth. Employment in an individual economy can be increased by intensifying the development and application of new technology on an increasingly wide basis in the various sectors of the society.

The enclosed Graph 1 shows the OECD employment by manufacturing industry 970-1993 in various industry groupings. Growing technology intensity is linked with an increase in highly trained and well-paid manpower.

The change towards an knowledge-intensive growth has been going on for a long time and is believed to go on accelerating. Knowledge-intensive manufacturing and services are the most dynamic sectors in the economics of the OECD countries. According to forecasts new information technology and related multimedia services may create millions of new jobs over the next few years in Europe.

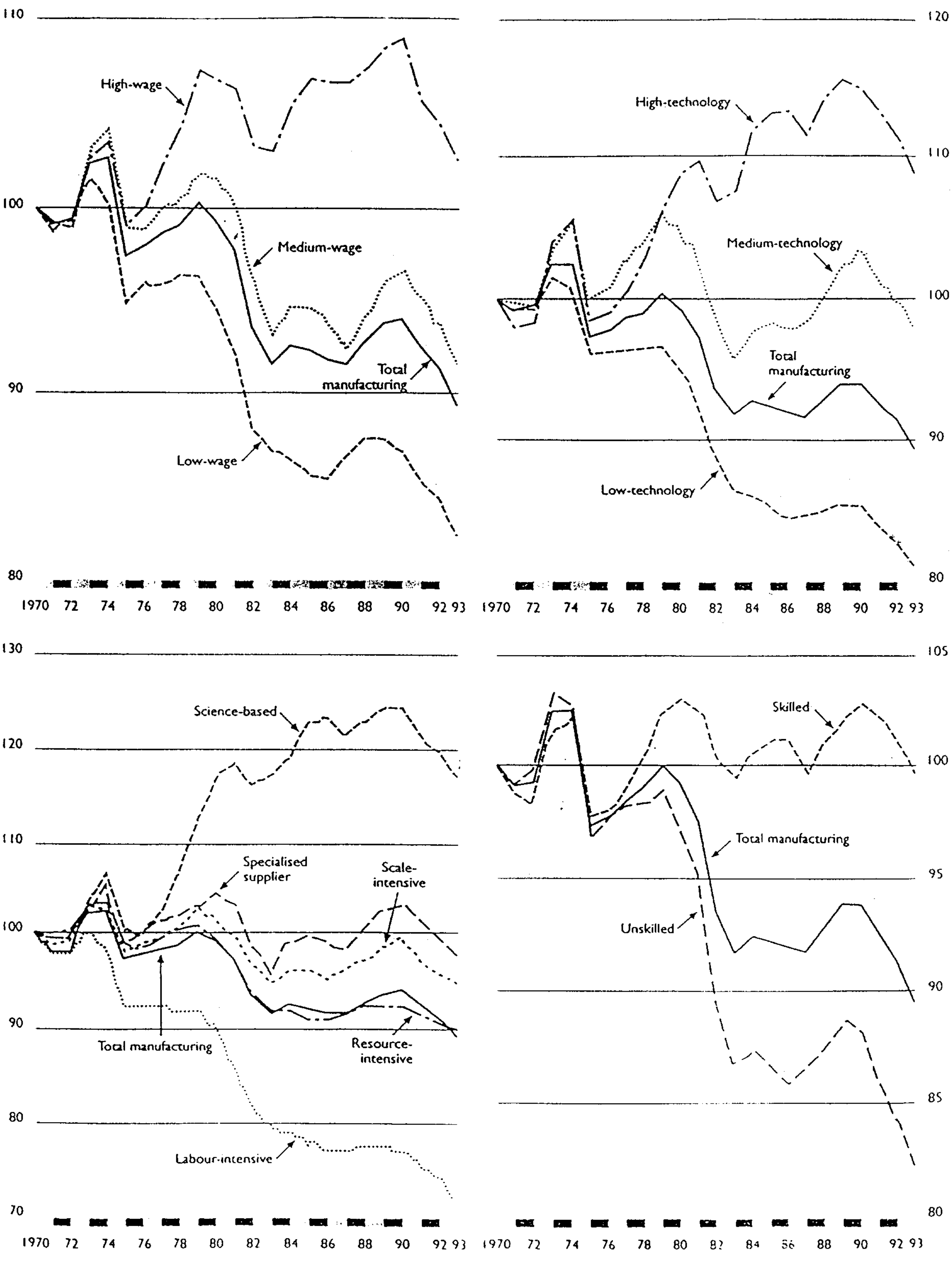
Besides between different industries, development towards an increased knowledge intensiveness is also taking place inside them. Firms that can exploit new technology effectively have also been able to improve their output, creating more new jobs than firms on average. Businesses' own ability to exploit technologies generated outside them depends in turn largely on their own research effort.

In the case of knowledge intensive manufacturing and services the trend has clearly been towards networking. This is characterized by a strong vertical integration, outsourcing and downsizing of operations. Units in the field are thus typically members of subcontractor networks and buyers of significant external services. In many knowledge intensive fields, such as multimedia services, the traditional limit between services and production is in fact gradually disappearing. The trend is toward clusters and leaning organizational structures. At the same time, it has been observed that knowledge intensive growth has extensive external effects within an economy for example in terms of productivity and employment.

The capacity for making use of technology and the new approach to production are interrelated. Data from individual firms testifies that the benefits to be derived from new technology in terms of raised productivity and/or jobs created require enterprises

Graph 1. OECD employment by type of manufacturing industry

OECD – 19 countries; index 1970 = 100



Source: OECD, STAN database (DSTI, EAS Division), March 1995.

to revise their production systems. Jobs are created by the knowledge intensive growth in both large and small and medium-sized companies, in many cases as a result of their mutual interaction. It has also been observed that so-called microfirms (with less than 10 employments) play a central role in this development process. This is an important observation in that these firms are often missing in sectoral and macroeconomic statistics.

Besides the knowledge-intensive growth, there is also another trend promoting job creation within the OECD. Jobs have been created especially in areas where the labour market has been operating flexibly enough. This growth category has, however, involved a decline in the wage level for low-wage blue-collar workers.

The whole of the OECD area is thus undergoing a polarization, even though the picture is not the same for each member state. Well-wage jobs are thus being created within knowledge-intensive branches of manufacture and services, whereas for tasks for which only limited skills are required the jobs created involve a low-wage level. The difference applies both among and within individual sectors. The OECD's own Jobs Study quotes an example of this general trend: up until recent years, Japan has been able to maintain a high rate of employment by developing her production structure actively toward higher value added products, in the Unites States, both high-skilled and low-skilled jobs have been increasing rapidly. The trend reflects an ability for structural adjustment as well as a flexibility of the labour market. In Europe the development has been dreary, due, both to an inadequate capacity to structural renewal and to inflexible labour markets and product market structures.

The OECD Jobs Study holds unemployment in the OECD countries to be structural rather than cyclic. Under these circumstances, macroeconomic policies alone cannot improve the situation. In fighting structural employment, the task of macroeconomic policy is only to create general conditions for an effective functioning of structural policies. In the case of measures relating to structural policy, OECD recommendations are divided into those of labour market policy and those relating to innovation policy. The central conclusion is that measures adopted in these three policy sectors have to operate simultaneously and mutually reinforcing each other. The ultimate goal is to improve the economy's innovative and adaptive capacity to adjust and create conditions for job creation.

Recommendations made by the OECD essentially reflect the finding that even in case the total number of jobs were primarily dependent on the price of labour, it is by no means indifferent for an individual economy whether jobs represents a low-productivity and low-wage level or a high-productivity and high-wage level, which last-mentioned have various repercussions on the rest of the society.

Developments in Finland

In the international perspective, the situation of Finland appears both positive and negative. A negative element is of course the high rate of unemployment. A positive feature is the fact that in Finland developments diverge from the European average. Finland has been able to make exceptionally radical changes in the structure of her output towards knowledge-intensive growth. The Finnish development in terms of the indicators discussed above for the whole of the OECD is seen in graph 2.

Finland has succeeded in converting the long development process into a virtuous development circle in industrial structure. Finland has, during the past few years, managed to move herself from the previous resource-based industrial structure toward a knowledge intensive growth. The business sector research effort has been growing exceptionally fast in Finland. Companies have improved their capacity to develop and exploit technology. Output and exports of high-tech products have grown more rapidly than in any other OECD member state. In the field of the manufacturing and application of information technology Finland belongs to the world vanguard.

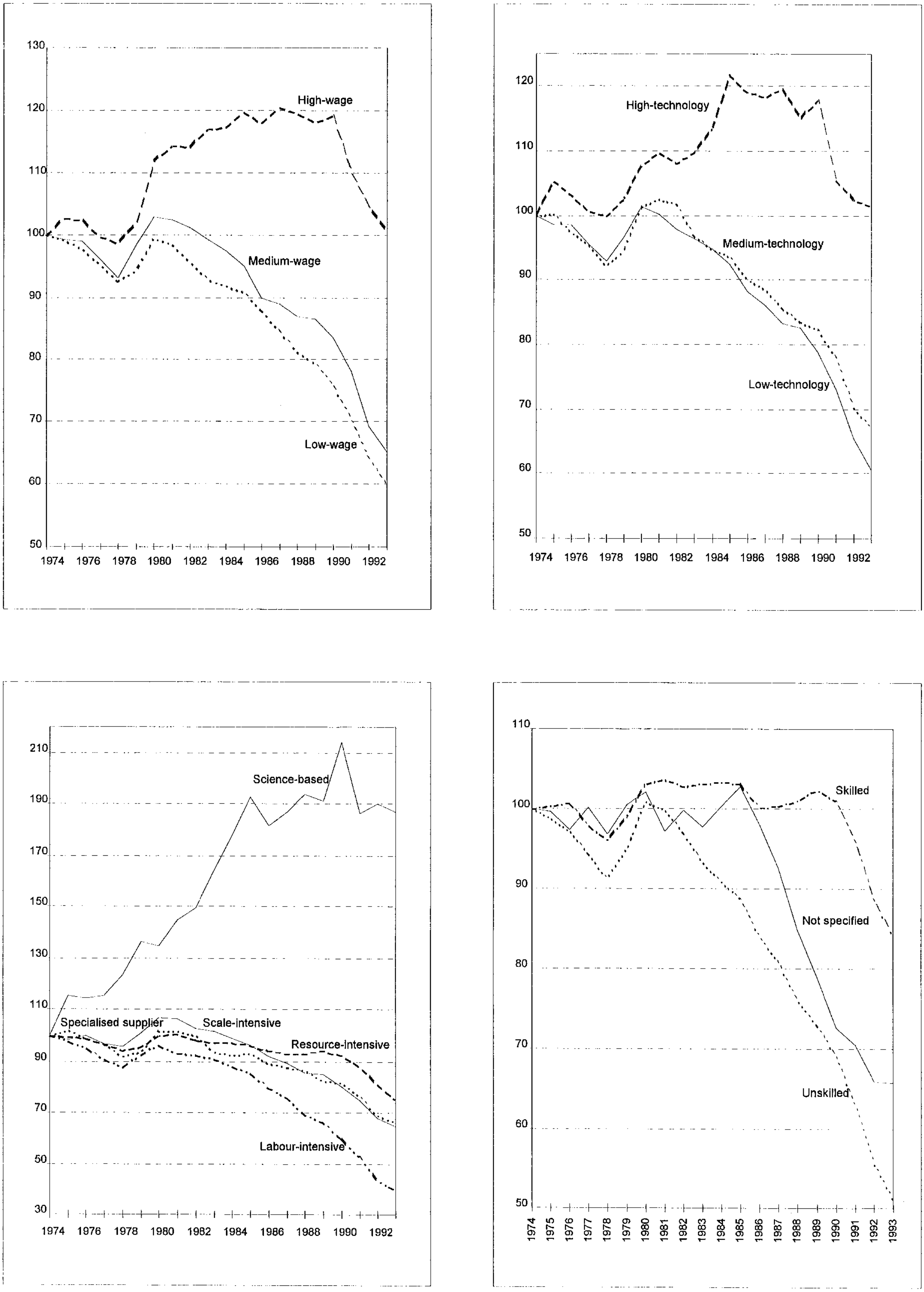
The top of this development process consists of certain multinational companies. These, however, are by now flanked by thousands of small technology firms. A very large part of them have assumed the practice of networking and established intensive co-operation with science and technology centers established in various parts of the country. In Finland as elsewhere, knowledge intensive manufacture and services have turned out to be the most dynamic part of the economy, affecting significantly the rate of employment at short as well as longer term.

The data of Graph 2 extend only to the year 1993. In that year, high-tech industries employed to some 40 000 people. The preliminary data after that year point to a very rapid growth in manpower of the high-tech manufacturing industries. According to the latest manpower calculations made by Statistics Finland manpower of electrical and electronics industries increased from 34 000 for the second quarter of 1994 to more than 44 000 for the corresponding period of 1995. During the same time, the manpower employed in the manufacture of instruments increased by ca 2 000, i.e.. by about 40%. Post 1993 data gathered from the science and technology centers in regard of knowledge-intensive jobs points likewise to a rapid growth.

The prospects of knowledge-intensive growth over the next few years have been assessed in two surveys. In 1994, the SITRA (the Finnish National Fund for Research and Development) published a report on the growth potential of small and medium-sized technology firms over the period 1993 - 1998. The Finnish Electrical and Electronics Industry (SETELI) in turn has made an estimate of the manpower requirements in its branch during the period 1994 - 2000.

SITRA's survey comprised 1 445 technology SMEs both in manufacture and services. The firms deemed their growth potential exceedingly high. They considered themselves capable, subject to propitious conditions of operation, of trebling their exports to 28 billion Finn marks and their labour force from the 48 000 people in 1993 to 74 000 by the year 1998. Technology companies supply specialized products and services into a market characterized by a rapid development, demanding customers, a short life span of products and, from the outset, highly international operations. One

Graph 2. Employment by type of manufacturing in Finland



third of the firms supply entirely novel products to entirely new markets, where the risks of failure are highest.

The growth of the enterprises covered by SITRA is hampered by their deficient capacity to develop qualitatively and technologically sufficiently sophisticated products which would generate a comparative edge and which their clients would be ready to pay for. Shortcomings in their skills and know-how are found in marketing, management and product development. No less than 40% of the aggregate finance requirements of the firms should be allocated to intangible investments which their own operational funding is sufficient to cover and which are bankable to a very limited extent. More than half of the intangible investments are in research and product development. Let's mention, for comparison, that only 15% of the finance is used for tangible investment in machinery and equipment.

One reason for covering SITRA's report at some length here is that it provides a good and comprehensive picture of the opportunities and problems involved by knowledge intensive growth. The findings are largely identical with those of various international reports.

In electrical and electronics industry the output has been estimated to grow from the 35 billion Finnmarks in 1994 to some 80 billion by the year 2000. During the same time, the entrepreneurs in the sector have considered that they would require about 5 000 new, high-skilled employees a year. At the moment, the combined annual output of graduates in the relevant fields is less than half of the estimated requirements of the industry. Part of the graduates, moreover, find their way to other sectors. Especially within university training it would be important to intensify and speed up the structural reforms under way.

The two surveys on the growth of knowledge-intensive fields, the results of which are supported by similar data provided by domestic science and technology centers as well as diverse foreign sources, permit the conclusion that the direct employment effects of this growth by the end of the '90s may amount to 30 000 - 50 000 new well paid jobs. This estimate does not yet include the jobs to be created within subcontracting and related business services. By domestic and foreign estimates, these should make 0.5 to 1.5 jobs for each job generated directly. This indirect influence will not be limited only to high-tech, high-skill and high-wage jobs.

From the point of view of national economy, knowledge-intensive jobs are of vital importance and value. The bulk of the knowledgeintensive output is exported and the relevant jobs are well paid. Thus the growth of the domain adds to the revenue from abroad and taxes for the economy, and creates considerable demand for domestic consumer services.

The Role of the Innovation System

The OECD recommendations for innovation policy to be followed are based, on the one hand, on the general observation that knowledgeintensive growth is of undeniable significance for the national economy and, on the other hand, on the practical experience that macroeconomic or labour market measures do not alone ensure adequate preconditions for knowledge-intensive growth.

Knowledge-intensive growth is promoted by various public innovation policy measures. These relate to research and training, competitive conditions, laws and regulations for protection of intellectual property, national and international cooperation networks, and technology transfer and exploitation. In addition, there is a need for measures with direct bearing on companies.

Experience of the necessity of corporate innovation policy measures is based on the observation that the market mechanism cannot, due to its shortcomings commonly known as market failure, ensure all preconditions needed for knowledge-intensive growth. Recent economic research has provided a forum for debate on other arguments as well.

Knowledge-intensive companies are forced to develop for the market ever new products and product variants and to allocate a significant part of their resources on research and product development. The high risks associated with product development, the inability of the market mechanism to reflect the full social benefits of research in prices, and the excessive resource requirements of research and development projects in proportion to companies' resources disincline companies to invest enough in research and product development. These traditional market failure elements connected with corporate research activities have seen on their side the rise of an inability of the financing system to finance intangible investment and ventures whose value is not based on tangibles but on a good idea and knowledge. In addition, SMEs often find it impossible to enter international markets and to acquire all the information needed to complete innovations all by themselves.

From a company perspective these are barriers to growth which cannot he removed by the entrepreneur alone. Afore-mentioned problems faced by technology companies and in the electronics industry provide good examples of such barriers.

Knowledge-intensive growth forms a dynamic development circle which cannot he ensured without adequate investment. According to international experience, its creation is a difficult as well as time-consuming process. Despite intensive efforts, many countries have failed in it. In Finland, generation of the circle has been the result of strenuous work, in which companies have been playing a crucial role. On the other hand, the process has been greatly helped by the consistent innovation policy followed. For example TEKES (The Technology Development Centre of Finland), the various universities, VTT (The Technical Research Centre of Finland), the various science and technology centres, and SITRA all play a significant role in the overall success. The good cooperation between businesses and the public sector, too, has contributed to the positive outcome.

The bulk of the innovation policy measures proposed by the OECD belong in the sphere of Finland's national innovation system. The innovation system is the main structural policy instrument, which should ensure preconditions for a knowledge-intensive growth in Finland. On one hand, the innovation system involves long-term operations based on extensive cooperation. On the other hand, it must provide a rapid means to tackle with problems raised by various topical issues. For an improved employment rate the critical and urgent measures consist of the safeguarding of an adequate and consistent finance for research and product development, meeting of the staff requirements due to the knowledge-intensive growth, alleviation of the financing and marketing problems faced by small and medium-sized technology firms, and intensification of technology diffusion and utilization.

The national innovation system has also other tasks in the domain of unemployment. Research must be conducted to find means for the fighting of the social exclusion phenomenon and for a correct measuring and structuring of unemployment benefit systems.

Summary and Conclusions

A knowledge-intensive growth constitutes the prime source of high-wage new jobs. Finland's position and capabilities to make use of these possibilities are exceptionally good. The virtuous development circle created for the knowledge-intensive growth in Finland through the long-term work carried out may, over the next few years, give rise to tens of thousands of new jobs.

As in the other OECD member states, unemployment is, in Finland too, a structural problem. Continuation of the knowledge-intensive growth is therefore one of the key prerequisites for the achievement of the employment targets of the government at short as well as longer term. International experience suggests that a balanced and progrowth macroeconomic and labour market policies are indispensable albeit insufficient measures for the elimination of barriers to growth.

Further development of the national innovation system must be incorporated into the national employment strategy adopted by the Government in Finland. The development of the Finnish innovation system will also be taken into account when the industrial strategy and the SME policy programme are to be revised. The most urgent measures within the sphere of the innovation system are the increase of R&D funding, a reform of the educational system needed for knowledge-intensive growth, alleviation of SMEs' financial and marketing problems, and an intensified effort to enhance the diffusion and utilization of technology.

OBSTACLES IN INTERNATIONALIZATION AND EMPLOYMENT GROWTH OF SME'S

Yrjö Toivola*

SME's and Large Enterprises in Finland

There are close to 200 000 enterprises in Finland, of which only 500 are large ones. The rest are SME's (employing at most 250) of which 20 000 are industrial. The interesting group are those industrial enterprises with R&D activities and consequently able to develop innovative products with competitive edge to enter international, even global markets. Such companies in Finland number about 2 000. These technology-based companies export high-technology products and can look forward to rapid growth.

Having mastered a technology or a number of technologies the technology-based enterprises are able to solve their customer problems innovatively using such technologies as tools. Technology-based innovation is the key to successes in international markets complemented with other business-skills leading to growth and profitability and to increased employment.

Finnish high-tech exports have grown most rapidly of all OECD-countries and are reaching this year about 20% share of the total exports of Finland.

In comparison with other EU-countries Finland seems to have deficiency in the number of SME's employing 10-500, the gap being about 10 000 such enterprises. Therefore almost a doubling is needed in this population. Technology-based SME's now number approximately 2 000. If the gap mentioned above would close they would number 3 000.

Characteristics of Technology-based SME's

According to a study by SITRA[1] technology-based SME's have following characteristics:

- half are microenterprises employing less than 10
- half are less than 10 years of age
- 2/3 are manufacturing companies
- exports are significant for all sizes

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1 Annareetta Lumme: Uusteollistamisen avaimet (Keys to reindustrialization), SITRA, 1994.

- educational level of personnel is high
- geographically spread as rest of industry.

These technology-based SME's are growing per annum
- 20% in sales
- 30% in exports
- 8% in personnel.

Consequently 1995 their
- sales were approximately 45-50 billion FIM
- exports 15-17 billion FIM (approximately 10% of total exports)
- employment 65 000 - 70 000.

The situation was 1995 approximately as follows

	Number	Sales (billion FIM)	Employees	Share of total exports	Annual increase in employment 1995-2000	
					direct	indirect
- Technology-based SME's	2 000	45	65 000	10%	5 000	5 000
- Electric/electronics industries	200	42	42 000	20%	5 000	5 000
- UPM Kymmene (largest forest company in Europe)	1	45	32 000	17%	-	-

Technology-based SME's are significant employers employing doubly as many for the same volume of sales in comparison with process type industries as can be seen in the above comparison table. These SME's as well as electric/electronics industries will almost double the number of jobs (direct and indirect) by the year 2000. This will account to about half of the Finnish Government's present aim to increase employment.

Economic growth is an important factor in employment. An increase of 0.8-0.9 million FIM in annual sales will add one direct job in technology-based manufacturing SME's, whereas 0.5 million FIM will suffice for software and technical service type SME's. As technology-based SME's are often well networked, they also create indirect jobs in subcontractor companies and in service sector. Technology-based SME's have grown rapidly and quietly on the fertile soil of the Finnish Innovation System. They are based on knowledge and skills (an inexhaustible source). Their innovative products sell also in recession times. Exports make these companies less dependent on economic conditions of any one country and improve the trade- and current-account balance of Finland. High-tech exports have exceeded imports in 1993 and 1994. Personnel is enthusiastic and dedicated.

Obstacles

In spite of impressive results, there are inhibitory factors hindering internationalization of technology-based SME's. These are of two categories related to
- size of enterprises
- infrastructure of the country.

As half of the technology-based SME's have sales less than 6 million FIM (1 million ECU) and staff less than 10, it is natural that the size and age have prevented the accumulation of some skills necessary for success in international markets. Although the technology is well understood and the staff is enthusiastic, dedicated and hardworking, there are deficiencies
- in general management skills like choosing the customer, goal setting and making strategic choices
- in specific skills, such as financing, manufacturing and markedly in sales and marketing.

Furthermore small companies
- are not known and
- lack in credibility.

Often they also are
- too modest and cautious (probably caused by the recent recession period), and
- home-bound for too long a time in small national market (instead of concentrating on one or a few selected standard products, fit for a series manufacture and suitable for global distribution).

There is one obvious deficiency in <u>the infrastructure</u> i.e.
- lack of equity financing.

It is estimated that technology-based SME's need about 6 billion FIM annually for financing their investments and growth. Half will be covered from operations, 1/3 as banks loans leaving approximately 1 billion FIM as an annual need for equity financing. Today only 10% of this need is covered and a true risk-sharing equity is about totally lacking.

An additional factor is that large majority (80-90%) of technology-based SME's are not members of employers' associations. Being young and small these companies apparently feel that traditional associations are not useful as their competitiveness stems from other sources than lobbying. Consequently their voice is not heard and their rightful place as an employment source and a source for growing exports is not fully reorganized and their needs are overlooked.

Support Programmes

Finland is in need of a 50% increase in number of technology-based SME's i.e. from 2 000 to 3 000. This can be achieved in less than five years by systematically scanning government sponsored research (over 5 billion FIM annually) for results, which may be transformed to businesses. This (with addition of ideas from other sources) should result in about 1 000 ideas leading to 200 new companies formed annually or ideas transferred to existing companies.

Such programmes already exist. SPINNO, now active at Innopoli Science Park, is looking for ideas in the region around the Capital now for the fifth year. Last year SPINNO evaluated 100 ideas leading to about 30 new businesses. Technology Development Centre (TEKES) has last year initiated similar programmes (TULI 95) in other Science Parks and Technology Centre locations.

Budget for these activities are less than 2 per mil of the governmental research budget and they can markedly improve the efficiency of the final portion of the Innovation System, without which it is not worthy of its name.

The other support programme aimed to fill the gap in management skills of SME's is the National High Technology Mentor Programme. It is operating at Innopoli Science Park, now for the second year on organized basis. This programme is a national know-how and knowledge transfer programme from experienced senior business managers to their younger colleagues on a voluntary basis. The programme has been targeted on high-tech SME's helping them into rapid international growth. The target group-size is 100 SME's with over 100 Mentors. Programme is now being expanded to include start-up SPINNO-companies.

Summary

During the past ten-fifteen years an important group of about 2 000 technology-based SME's has been borne in Finland with growing international market offering significant employment. There are practical support programmes to increase the number of these companies and help them to rapid, international growth (SPINNO, TULI and MENTOR).

An annual need of equity financing for internationally oriented SME's of 1 billion FIM is hopefully coming from privatization of government owned industries (320 million FIM fund already exists), from insurance companies and pension funds and from private sources. However, additional measures are urgently needed to remove this barrier for growth in internationalization of technology-based SME's.

SUPPORTING THE CONSOLIDATION AND INTERNATIONALIZATION OF SME'S - THE SYSTEMIC PERSPECTIVE

Erkko Autio*

Introduction

The infrastructure for supporting the emergence and consolidation of SMEs has expanded rapidly during the 1980's and 1990's. This expansion reflects the increased attention that the SME sector has received in industrial and technology policy. In particular, the considerable employment generation potential of the SME sector has provided an important inducement for the introduction of such support measures. In Finland, the increase in interest shown toward SMEs, high technology small firms in particular, has been particularly steep. In 1995, the Ministry of Trade and Industry launched the "Yrittäjyyden vuosikymmen - Decennium of entrepreneurship" initiative, striving to orchestrate the efforts and support aimed at inducing growth and prosperity in the SME sector.

The problem of supporting the internationalization processes of SMEs is thus timely and relevant. The wealth generation potential of the technology intensive SME sector in particular can be important. As the amount of resources directed at inducing growth and prosperity in the SME sector is considerable, it is important that SME support mechanisms be continuously improved in order to obtain the highest potential return for this investment.

In the present article, I propose to present evidence suggesting that

1 the employment generation potential of the new, technology-based firm sector is an important one and surprisingly recession-proof

2 "systemic" barriers to growth among SMEs may play a more important role than hitherto recognized.

The implication of these findings is that a more systemic approach should be assumed also when developing SME support and consolidation policies. The present paper argues that while the rapid expansion of the SME support infrastructure has been justified, there may remain areas of further improvement. The main argument of the present paper is that the existing support measures may still largely reflect the linear view of the spin-off process of SMEs. In this view, the SME is expected to go through a certain sequence of stages during its evolution. The points put forward in the present paper are that

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1 the evolution of SMEs is not linear, but essentially *configurational* in character, and support measures should reflect this characteristic

2 the trend toward more evenly distributed value creation processes in industrial value creating systems means that *systemic constraints* increasingly regulate the emergence and evolution of SMEs. In particular, the trend toward increased *technological and manufacturing embeddedness* creates a need to revise these existing support measures.

It is not a gross oversimplification to state that the existing SME support measures still are predominantly resource-push measures that are geared toward supporting linear growth processes within the SME sector. The problem of creating systemic support measures, that take systemic constraints into account, merits more attention than what it has been given so far.

The focus of the present discussion will be mainly on high technology industrial sectors.

Economic Importance of the Technology Intensive SME Sector in Finland

There have been only few surveys that have attempted to take an overview of the technology intensive SME sector, or the NTBF (new, technology-based firm) sector, in Finland. Perhaps the most ambitious effort was undertaken by SITRA, the National Foundation for Research and Development of Finland, in 1994[1]. The SITRA survey compiled data on 392 "technology intensive" SMEs, from a population that had been nominated by regional expert panels. The expert panels had been requested to nominate SMEs that they deemed to possess good "potential for rapid growth". The expert panels nominated altogether 1095 such SMEs.

The SITRA survey produced some quite interesting findings. Among these are

- as many as 45 % of manufacturing SMEs employing from 0 to 4 employees were engaged in export activities
- all manufacturing SMEs employing more than 100 employees were engaged in export activities
- in the best possible growth scenario, based on the estimate of the firms themselves, the firms would more than double their sales within the next five years, i e, by the end of year 1998. This represents a compounded annual sales growth of 20 %
- the most important growth potential was found to be in the group: "cutting-edge technologies". This group roughly covers industry sectors traditionally labeled as "high tech"
- internal growth barriers in the firms were predominantly competence related, i e, indicating a lack of relevant competencies within the firm. The external growth

1 Lumme, A, Uusteollistamisen avaimet (Keys to reindustrialization), SITRA, Helsinki, 1994.

barriers were predominantly funding related, i e, indicating a lack of available capital, or a too high price of it

- the growth strategy of most SMEs was either to aspire for modest growth, or to aspire for the best possible growth that still could be funded using own cash flow. The firms were found to be surprisingly reluctant to accept funding from external sources.

It should be remembered that the SITRA survey explicitly focused on a small sub-section of the SME population in Finland. Only high potential SMEs were included in the survey. In this light, the best possible growth expectation indicated by the firms, 20 % per year, is a modest one. It is even disappointingly so, taken the great hopes that are attached to this group of firms.

Another estimation of the economic importance of the NTBF sector in Finland is being carried out by the Center for Technology Management of Helsinki University of Technology[2, 3]. At the time of writing the present paper, the analysis is still very much under progress, and it is only possible to present preliminary, tentative conclusions.

The estimation carried out by the Center for Technology Management is being prepared for the EU DG XIII, in a consortium co-ordinated by the University of Warwick. The consortium compiles data on the size distribution of firms in high technology sectors in EU countries. The consortium has picked a group of industry sectors that can be considered as high technology sectors in the NACE classification. As the NACE classification has only been used in Finland since year 1994, the TOL 88 classification was used instead. The conversion table between the NACE classification, as used by the Warwick consortium, and the TOL 88 classification, as applied in Finland, is shown in appendix 1.

In table 1, preliminary findings from the analysis of Finnish data are shown. The data is shown in the present paper for the first time.

The table lists the size distribution of firms in high technology sectors in Finland in 1986 and in 1993, thus making it possible to detect possible changes in the economic importance of NTBFs in Finland during these years. In table 1, NTBFs a defined as SMEs (<500 employees) operating in high technology sectors. A comparison between years 1986 and 1993 is particularly interesting, since the most severe peacetime recession ever encountered in Finland occurred during this period. Year 1986 was the year when the bubble economy phenomenon in Finland was reaching its peak. Year 1993 was one of the most depressing years of the economic recession, from which Finland is still recovering.

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2 Autio, E, Review of empirical knowledge on the economic importance of new, technology-based firms in Finland, Helsinki University of Technology, Center for Technology Management, Research reports 9516, Espoo, 1995.

3 Autio, E, Country data on NTBFs in Finland, Helsinki University of Technology, Center for Technology Management, preliminary task report, Espoo, October 20, 1995.

Table 1 Firms in high technology sectors in Finland by size class in 1986 and in 1993

Size class	Firms **1986**	Firms **1993**	Change	Employees **1986**	Employees **1993**	Change	Annual sales **1993, kFIM**	Sales per employee **1993, kFIM**
0 - 4 employees	2 434	3 968	63 %	4 104	6 153	50 %	2 030 040	330
5 - 9 employees	678	853	26 %	4 342	5 532	27 %	2 308 155	417
10 - 19 employees	415	365	-12 %	5 377	4 834	-10 %	1 977 315	409
20 - 49 employees	230	196	-15 %	6 832	5 755	-16 %	3 048 537	530
50 - 99 employees	70	89	27 %	4 865	6 215	28 %	4 151 382	668
100 - 199 employees	39	45	15 %	5 411	6 337	17 %	4 153 659	655
200 - 499 employees	28	36	29 %	8 464	11 353	34 %	6 057 835	534
500 - 999 employees	12	6	-50 %	7 961	4 150	-48 %	2 738 427	660
100 - employees	7	11	57 %	18 311	26 588	45 %	65 953 702	2 481
Totals	3 913	5 569	42 %	65 667	76 917	17 %	92 419 052	1 202

Table 1 shows that in spite of the severe economic recession, the high technology sectors in Finland have managed to increase in economic importance, both in absolute and in relative terms. The overall employment of these sectors has increased by 17 %, in spite of the severe economic recession. The progress is particularly impressive among the group of micro firms, employing less than 10 employees, the number of which has increased by 55 %, to 4 821 firms. At the same time, the total number of people employed by this group has increased by 38 %, to 11 685 employees. Also large high technology firms had made significant progress in spite of the economic recession. An important part of this progress should be attributed to one firm, though.

The most important potential of the NTBF sector seems to be in employment generation. Table 1 shows that high technology SMEs (employing less than 500 employees) employed 70 % of the overall workforce in these sectors, while generating only 25,7 % of the total annual sales. The 7 firms in the largest size class, while representing only 0,2 % of the total number of firms and employing 34,6 % of the overall workforce, generated 71,4 % of the overall sales in these sectors. The contrast between employment creation and sales generation is an interesting one and calls for closer analysis.

The last column of table 1 is particularly interesting. The last column indicates the volume of sales per employee generated in each size class. The column shows that the volume of sales generated per employee is substantially higher for the size class of 1 000 or more employees than for the other size classes of firms. The volume of sales generated per employee in the size class of 1 000 or more employees is over 300 % higher than for the other size classes. This drastic difference gives reason to suspect that an important fraction of the value added generated in the smaller size classes is actually transferred as inputs into the complex product systems maintained by a few large systems integrator firms, such as the Nokia Corporation. If one takes a look at the more successful SMEs in the OTC list of the Helsinki Stock Exchange, one will be surprised by the large number of SMEs that actually act as subcontractors to Nokia Corporation.

The available data does not allow us to check the fraction of sales generated by NTBFs that is provided as inputs into complex product systems maintained by large systems integrator firms. The finding by Olofsson and Wahlbin, however, gives reason to suspect that this fraction is not negligible. Studying university spin-off firms in Sweden, Olofsson and Wahlbin found that university spin-off firms provide a substantial part of all research and development subcontracting that was sourced by established Swedish firms from Swedish industries and branch organizations[4]. This is an important indication of the networking tendency in the Swedish economy. The finding of Olofsson and Wahlbin strongly suggests that NTBFs have a strong tendency to become attached to external technology supply networks maintained by a few, large systems integrator firms. Looking at the phenomenon from the other side of the window, Patel and Pavitt present compelling evidence that the competence portfolios of systems integrator firms are rapidly developing to allow for the creation and maintenance of technologically dispersed networks of external technology suppliers[5].

The above described trend toward more integrated value creating systems, which is in many ways reflected in the characteristics of the population of new, technology-based firms, has prompted arguments advocating a more systemic approach to research on NTBFs[6]. Essential to the systemic approach is that the NTBF is viewed as a concentration of technological competencies, that is linked to a broader external competence structure, sometimes denoted as a technological system[7]. In the systemic approach, the interactions between the firm and its operating environment are emphasized.

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[4] Olofsson, C, Wahlbin, C, Teknibaserade företag från högskolan, Institute for the Management of Innovation and Technology, Linköping, 1993.

Olofsson, C, Wahlbin, C, Firms started by university researchers in Sweden - Roots, roles, relations, and growth patterns, in: Frontiers of Entrepreneurship Research, Babson College, Wellesley, 1993.

[5] Patel, P, Pavitt, K, Technological competencies in the world's largest firms Characteristics, constraints, and scope for managerial choice, STEEP Discussion Paper No 13, University of Sussex, SPRU, May 1994.

[6] Fontes, M, Upgrading national systems of innovation: New, technology-based firms, a vehicle of technology transfer and absorption at country level, Third International ASEAT Conference, Manchester School of Management, September 6 - 8, 1995.

Lindholm, Å, The economics of technology-related ownership changes: A study of innovativeness and growth through acquisitions and spin-offs, Doctoral Dissertation, Chalmers tekniska högskola, 1994.

Autio, E, 'Atomistic' and 'systemic' approaches to research on new, technology-based firms, Small Business Economics, 1995 (forthcoming).

Stankiewicz, R, Spin-off companies from universities, Science & Public Policy, vol 21, (2:1994). pp 99 - 107.

[7] Carlsson, B, Stankiewicz, H, On the nature, function, and composition of technological systems, Journal of Evolutionary Economics, vol 1, (1991), pp 93 - 118.

The systemic dependencies of NTBFs are reflected in many ways, at least some of which bear relevance for the discussion of SME support policies. For example, in Finland, in the Finnish electronics industry, almost all of the major pioneering NTBFs had been acquired by larger firms. Among the major new pioneers in 1989, only one company, Vaisala Corporation, was still independent[8]. The composition of the Finnish electronics industry in 1989 is shown in figure 1[9].

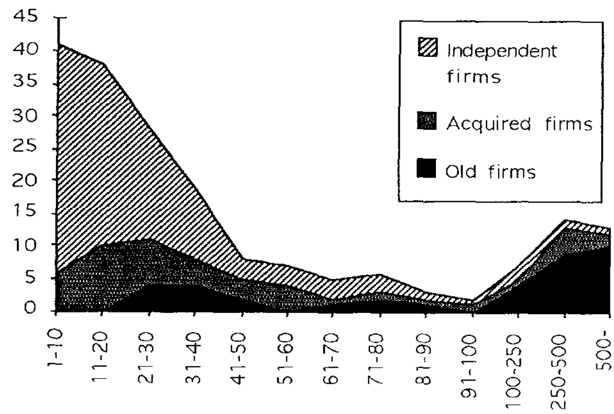

Figure 1 *Firms in the electronics industry in Finland in 1989 classified according to number of employees*[10]

In figure 1, it would seem that a comparatively large proportion of those companies that grow to employ more than 50 employees have been acquired by a large firm established initially in another industry and present in the industry already for a longer time. A similar result was found in another study carried out in 1994.

8 Lovio, R, Evolution of Firm Communities in New Industries, doctoral dissertation, Helsinki School of Economics and Business Administration, 1993, p 235.

9 Figures 1 and 2 are from Laamanen, T, Autio, E, Technology transactions within networks: The case of acquisitions of new, technology-based firms, European Conference on Management of Technology, Aston Business School, July 5-7, 1995.

10 Data from the database of Lovio, R, Evolution of Firm Communities in New Industries, doctoral dissertation, Helsinki School of Economics and Business Administration, 1993, p 235.

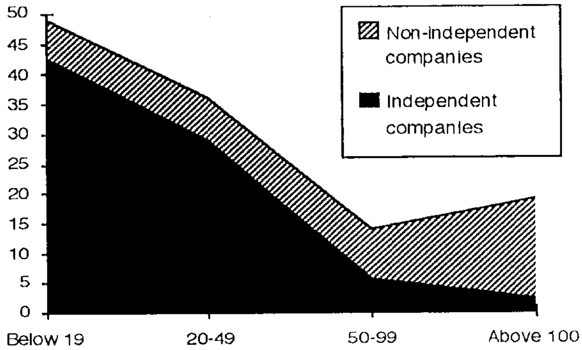

Figure 2 *Medium-sized firms in Finnish production oriented new technology industries in 1994 classified according to the number of employees*[11]

Figures 1 and 2 can either be interpreted both as evidence suggesting that there is not enough capital available to support the indigenous growth of NTBFs, and as evidence suggesting that systemic factors do regulate the evolution of NTBFs. The first explanation attributes the finding to the lack of a largely undifferentiated factor of growth, namely, equity capital. The second explanation attributes the finding to the existence of dominant dynamic complementarities[12] between small and large firms, the balance of which is disturbed when the small firms embarks on a rapid growth path. Both explanations are likely to be equally valid. There seems to be a lack of growth inducing equity capital in Finland, on the one hand, and the best route toward rapid growth often seems to be realized through acquisition.

The rapid decrease in the fraction of independent NTBFs after the size barrier of 50 employees is an interesting finding. It would seem quite logical that during the early phases the small, technology-based firm would try to preserve its identity by preferring collaborative arrangements with larger firms. The collaborative arrangement would also benefit the large firm. The large firm would have an option on the new technology without having to commit to it fully. As the small firm reaches the size of 50 employees, its internal competence pool ceases to be overtly influenced by a few individuals only, and its acquisition becomes less risky for the acquiring firm.

Linear and Configurational Views of the Evolution of SMES

In the traditional body of research on new, technology-based firms, the bias toward high growth firms is overwhelming. This means that a large fraction of the traditional body of research reflects the linear view of the spin-off process of these firms. The

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11 Data from Hyvärinen, M, Credit rating of medium sized companies in Finland, Report to be published in the series of the Finnish Ministry of Trade and Industry, 1995, p 64.

12 Rothwell, R, Innovation and firm size: The case of dynamic complementarity, Journal of General Management, vol 8, (6: 1983), pp 5 - 25.

linear view of the spin-off process of new, technology-based firms can be summarized as follows

1 a [technology-based] idea is invented

2 a new firm is established to exploit the idea

3 the new firm gathers resources and starts developing its business activity

4 if the business idea of the firm turns out to be viable, the new firm starts to aggressively pursue rapid growth.

In the linear view, it is assumed that there is a natural sequence of stages that a new firm goes through during its early existence. These stages follow sequentially each other in time, and every firm is expected to pass each stage. The natural tendency of all new firms, it is expected, is to pursue organic growth, i e, to amass resources. The linear view of the early evolution of SMEs is illustrated in figure 3.

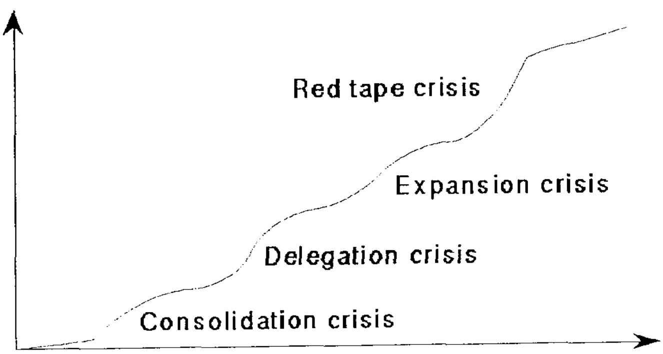

Figure 3 Illustration of the linear evolution model of SMEs

Essential to figure 3 is that the early crises are expected to follow each other as a sequence as the time passes. The point of the configurational view, that better reflects the reality of SMEs, is that there is no natural "sequence" of "stages" that every SME naturally tends to go through. Rather, there is a set of stable organizational configurations that are available for SMEs, and an SME may lock-in to any configuration for long periods of time[13]. The configurations may drastically differ from each other in terms of technology orientation, ownership, financial structure, growth orientation, strategies pursued, long-term goals. As the configurations are stable, the forces required to trigger a configurational transformation may be considerable. The configurational view of SMEs is illustrated in figure 4.

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[13] Raffa, M, Zollo, G, Caponi, R, Organizational transformations of small innovative firms, Babson Conference for Research in Entrepreneurship, London, April 14 - 16, 1995.

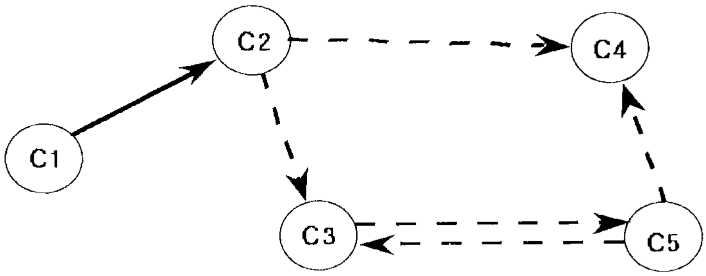

Figure 4 Configurational view of the evolution of SMEs. C1...C5 represent alternative configurations

The new industrial paradigm seems to favor the emergence of complex product systems[14], in which inputs representing several basic technologies are integrated. The rapid increase in the number of new, technology-based firms, we believe, can at least partly explained by the influence of this trend on industrial organization. To understand this development, it is necessary to study factors underlying the high degree of *technological embeddedness*[15] that characterizes many a new, technology-based firm.

Technological embeddedness is the result of the process by which a new, technology-based firm becomes immersed into the business system in which it operates. The process of becoming immersed into a business system often involves adaptive context-specific adjustments in the competence pool of the firm. In order to provide the best possible fit with the business system, the firm often adjusts its routines and operations, acquires context-specific information and knowledge, makes context specific investments, learns to know customers' systems, products, and processes, develops trust, expands its contact network, enhances its reputation. Many such assets are more or less context specific and not easily implemented into new contexts as such. Thus, the process of becoming tightly embedded often also means that many assets of the firm become idiosyncratic, with little of no value outside the context in which they have been created. The phenomenon of embeddedness is illustrated in figure 5.

[14] Hobday, M, Complex system vs.mass production industries: A new innovation research agenda, mimeo, University of Sussex Science Policy Research Unit SPRU, June 1995.

[15] Autio, E, Technological and manufacturing embeddedness among traditional and high technology small firms, 3rd International Conference on High Technology Small Firms, Manchester Business School, Manchester, September 18 19, 1995.

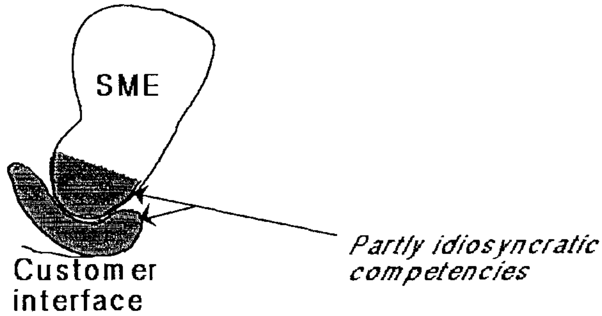

Figure 5 The phenomenon of embeddedness

The Need for Systemic Support Measures

The linear view of the early evolution of SMEs, as illustrated above is, of course, oversimplifying. Yet, analogous characteristics can be observed in the existing support measures geared to supporting the emergence and consolidation of new firms. These include

1 they are resource-push measures, i e, resources [such as money] are made available for SMEs in order to facilitate their growth

2 interactions between small and large firms are not given much explicit consideration

3 it is not recognized that high technology small firms in particular tend to become organic parts of external technology supply networks

4 the influence of systemic factors, that regulate the growth of SMEs through the process of becoming tightly embedded in networks, tend to be neglected

5 the evolution of SMEs is assumed to be linear, i e, proceeding relatively smoothly from one stage to another. Even though it may be recognized that turbulent phases may be encountered between phases, it is still assumed that there is some kind of natural succession of stages that each SME should go through during their evolution

6 support measures for supporting the emergence of high technology small firms tend to be technology-push measures, i e, it is assumed that there exists a large pool of public technologies, that need to be commercialized.

The use of such measures is justified, and many of them have proven to be highly effective. As the trend toward quasi-integrated value creating systems is likely to continue, however, it is proposed that new measures could be developed to complement the existing ones. It is proposed that new support measures be developed with the following characteristics

1 they are co-operation pull measures, i e, the locomotive effect of a few large systems integrator firms is actively sought and exploited

2 interactions between small and large firms are given active and explicit consideration. I e, synergistic situations are sought in which the operational advantages of small firms and resource-based advantages of large firms in innovation are combined

3 it is acknowledged that most high technology small firms tend to become parts of external technology supply networks. Thus, in order to understand the needs of the firm, it is necessary to understand the needs of the systems integrator firm

4 the influence of systemic factors, i e, the regulating influence of the network, is given close attention. It is acknowledged that the large systems integrator firm acts as the locomotive that pulls the technology supplier firms to growth. The policy support is geared to supporting the optimal evolution of the system of technology suppliers and systems integrators

5 it is acknowledged that the evolution of SMEs is essentially non-linear, or configurational in character. This means that SMEs have relatively few, stable configurations into which they may lock in for long periods of time. There is not necessarily any natural sequence in which the firm should go through different configurations

6 the influence of market pull forces is increased in the support measures geared to supporting the emergence of high technology small firms. This means that the pull effect of firm clusters is actively sought and exploited.

In the systemic perspective, the notion of success is expanded to incorporate continued technological excellence in addition to rapid organic growth. In order to support the achievement of sustainable technological excellence, the enhancement of the absorptive capability of SMEs needs to be supported. The need of such measures is becoming incerasingly recognized by national and transnational policymakers and think tanks, such as the OECD.

Examples of Possible Systemic Support Measures

The above discussion gives some clues as to what kind of support measures could be developed in order to better accommodate the systemic view. Examples of such support measures include, for example,

1 measures that are designed jointly with large industrial players in the region. Large systems integrator firms have a constant need to support the emergence of positive externalities, i e, external technology supply networks and manufacturing subcontracting networks. Such measures could incorporate, for example,

- licensing of technologies developed by the large firm to the emergent SME (a practice introduced by, for example, Daimler-Benz)

- people transfer between the large systems integrator firm and the emergent technology supplier firms in order to facilitate the consolidation of the emergent technology suppliers
- spin-out of support activities and enabling technologies from the systems integrator firm

2 measures that facilitate the configurational transformations of SMEs, when they occur

3 measures that are tailored for different configurations of SMEs. Such measures should be complemented with forms that facilitate the identification of different configurations

4 measures that target networks, or clusters of firms. Such measures could either aim at enhancing the emergence of firm clusters, or at shaping the firm clusters in an optimal way

5 measures that actively seek to combine technology push and market pull forces in a specific technological sub-system. For example, the production of public sector technologies in the form of student assignments could be linked with the need of systems integrator firms to create positive externalities. In such a model, universities would produce seeds for new firms that automatically could benefit from the market pull forces maintained by the systems integrator firm

6 measures that help the technology supplier firm become more independent after a certain size has been reached under the protective umbrella of the systems integrator firm.

In short, in addition to targeting individual firms, new support measures should be developed to target clusters of firms and technology supplier networks co-ordinated by large systems integrator firms. The participation of large systems integrator firms in developing such networks should be actively sought for. It is in the interest of large systems integrator firms to encourage the emergence of positive externalities, i e, external networks of technology suppliers, especially in technologically turbulent areas. In such networks, the locomotive effect of the systems integrator firm could be exploited. That is, the technology supplier firms could grow in the shelter offered by the systems integrator firm, and at a suitable stage become more independent, i e, start looking for other customers outside the technology supply network.

Appendix 1 Conversion table between NACE and TOL 88 sectors

NACE classification	TOL 88 classification
2514 Synthetic resins and plastics	1830 Resins and plastics 1850 Artificial fibers
2515 Synthetic rubber	1840 Rubber
2570 Pharmaceutical products	1870 Pharmaceutical products
3301 Office machinery	2610 Data processing equipment and office machinery
3302 Electronic data processing equipment	Included in 2610
3420 Basic electrical equipment	2621 Electronic components and circuits
3441 Telegraph and telephone and equipment	2622 Communications technology equipment 2624 Voice and image storing equipment
3442 Electrical instruments in control systems	Included in 2642
3443 Radio and electronic capital goods	2623 Radio equipment and television sets
3444 Components other than active components mainly for electronic eq't	2639 Other electrical equipment
3453 Active components and electronics sub materials assemblies	Included in 2639
3640 Aero space equipment manufacturing and repairing	Not relevant for Finland, only two manufacturers
3710 Measuring, checking, and precision instruments and apparatuses	2642 Measuring, monitoring, and control equipment
3720 Medical and surgical equipment and orthopedic appliances	2641 Medical and surgical equipment and orthopedic appliances
3732 Optical precision instruments	2643 Optical instruments and photographic instruments
3733 Photographic and cinematographic equipment	Included in 2643
7902 Telecommunications	5810 Telephone operator services 5820 Other data transmission 5830 Program transmission 5840 Services supporting telecommunications operators
8370 Professional and technical services not elsewhere specified	7190 Other technical planning and technical consulting services
8394 Computer services	7210 Computer services 7220 Computer programming services 7230 Data bank services 7290 Other data processing services
7310 Research and development in natural science and engineering	8610 Research and development 8620 Support services for research and development
7420 Architectural and engineering activities and related technical	7121 Technical services for landscape and water engineering 7122 Architectural services 7123 Structural engineering services 7124 Water, air, and heating technical services (?) 7125 Electrotechnical planning services 7126 Other engineering technical services 7130 Machine and process technical services
7430 Technical testing and analysis	Included in 8620

EXPERT KNOWLEDGE AS AN INFORMATION SOURCE OF FUTURE GENERIC TECHNOLOGIES

Osmo Kuusi*

The Economic Significance of Technology Foresight

Nelson (1993) explains the current strong interest in national innovation systems by pointing out that a "Schumpeterian innovator", the first firm to bring a product to market, is frequently not the firm that ultimately captures most of the economic rents associated with the innovation. It is often a set of institutions, whose interactions determinate the economic results of innovation activities. We may call this set of institutions and persons interacting in them a "technological community" (Nelson 1993) or a "developer community" (Kuusi 1991). The cumulative character of the process of technical change reflects the phenomenon that interactive learning is at the center of the process of technical change. Individuals and organizations increase their knowledge in technical matters not in isolation from each other (Edquist - Lundvall 1993). Edquist and Lundvall use the concept "development block" originally proposed by Erik Dahmen. Development blocks form frameworks for interactive learning.

In the book National Innovation System, A Comparative Analysis (Nelson 1993) the national innovation systems of different countries are presented and compared by many writers. In a retrospective article in the book Nelson asks what is required for an effective innovation system of a nation. Nelson summarizes that there are two major generally valid prerequisites for effective innovative performance.

The first prerequisites are strong and competent firms hardened by competition. They are competent in product design and production and they usually also have an effective overall management, ability to assess consumer needs and links into upstream and downstream markets. In most cases significant investments lay behind these firm capabilities.

Although public intervention has sometimes played an essential role in innovation activity, firms have had decisive roles in making of competitive products or production processes. Governments have sometimes had decisive roles in establishing of competent firms. For example, in Japan an important policy initiative was taken in 1936. The government restricted the production of cars to licensed companies, Toyota, Nissan and (later) Isuzu, who received financial and other support (Odagiri - Goto 1993). In Finland the national oil company Neste has been an example of successful public intervention.

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The other prerequisite of an efficient national innovation system has been education and training systems that provide innovative firms with a flow of people with the requisite knowledge and skills.

Public interventions both in advancing competitiveness of firms and education have, however, often been unsuccessful. Often the reason has been an insufficient conception of the types of skills needed and what features competent production has in the future. Nelson (1993) explains some of the failures in the following way:

> Although national programs have tended to focus on areas such as semiconductors, computers, and new materials, where technical progress is clearly dramatic, much of the economic value created by these advances occurs downstream, in the industries and activities that incorporate these new products into their own processes and products... it can be argued that active government policies often can be more effective when aimed to help an industry to take advantage of new upstream technologies than when oriented toward subsidizing major breakthroughs... (High-tech) advances... provide building blocks, the key opportunities for technical innovation in a wide range of downstream industries.

What do these arguments mean for technology foresight? We may define the general purpose of technology foresight in the following way:

Technology foresight tries to promote interactive learning of developer communities of generic technologies in order to find downstream applications and it helps to define skills needed in the future.

In this definition the concept "developer community" is used in the broad sense as also potential members of it.

Innovation Processes and Developer Communities

Rational technology foresight means trying to discover possible new innovations from already made inventions, innovations and production decisions and from realized and potential market demands. In practice this endeavour often means a study of phases of innovation processes. As Edquist and Lundvall (1993) have noted it is often difficult to make a clear-cut distinction between development and diffusion or the making of inventions and diffusion of innovations. Especially in technology foresight it is better to analyze innovation processes than the impacts and diffusion of single inventions or innovations. One may from earlier phases of an innovation process look forward to later phases.

A key concept in technology foresight is **generic technology**. This concept can be characterized by using a biological analogy. Let us draw a parallel between an invention and a gene. In biology a gene is the part of DNA which codifies the production of a single protein (e.g. Kuusi 1991). The "idea" of a gene is to be the smallest discernible functional unit of DNA , which is a "memory" of a cell.

As a gene with other genes, so an invention can function well only together with some other inventions. A generic invention means that the same "invention gene" can function in many different types of products or production processes. If a product or production process, where an invention X is applied is successful in the market, we may call in analogy with Freeman (1982) the new product or production process an innovation based on invention X. In analogy with a generic invention we may speak about a generic innovation or a generic technology. A generic technology functions well in many different types of products or production processes. Fusfeld (1978) illustrates this idea in the following way:

> When we talk about technologies, we tend to speak of specific techniques and products - internal combustion engines, refrigeration, air conditioning, for examples. But technology flows in and out of such products as these , and they do not provide the fundamental basis by which to measure technological change. The analysis must be on the level of **generic technologies**. A carburetor, for example, is an application of generic technology of vaporizing a liquid and mixing it with a gas. The same technology applied in the paint industry might become an automatic paint sprayer or in the aerospace industry a jet backpack.

Like Fusfeld I prefer to use the concept "technology" more generally than the concept "technique". A technology includes both the target(s) and means to achieve the target(s). A technique refers only some way to achieve target(s). If a exactly same method is used to achieve many targets we could speak about a generic technique. This interpretation is analogous with the original use of the concepts technology and technique (Volti 1992, Autio 1995). The word "technology" is derived from the Greek words "techne" and "logos". The word techne can be interpreted as skill of hand or technique. The word logos means knowledge or science. Thus technology can be viewed as a knowledge of skills or techniques. Knowledge of a technique includes also the targets for which the technique can be used.

It is commonly recognized that there are two basic types of innovation processes: science push and demand pull. Irvine and Martin (1984) has depicted these two models of innovation in the following way:

SCIENCE PUSH

Curiosity-oriented research --> Applied research --> Experimental

development --> Innovation

DEMAND PULL

Market demand --> Applied research --> Experimental development --> Innovation

An innovation process, which is based on the "science push" model, begins often from a promising generic technology. The driving force is the idea that an invention which has been successful in other connections (e.g. the use of microprocessors), may be useful also in this particular connection. The biological parallel of the idea of the science push model of innovation is a good synergism of a new gene and old genes. In the "demand pull" model the starting point is market demand. The biological parallel is a selection process of organisms in a changing environment.

There are many ongoing invention or innovation processes based on a particular generic technology at the same time. People involved in any of them are also participating in a developer community based on that particular generic technology. In technology foresight studies it is often practical to bundle together the technological communities of many closely interconnected technology communities (the developers of "many interacting genes"). We may e.g. speak about the technology community of the new biotechnology. It is a developer community of e.g. the recombinant-DNA-technology, cloning techniques, monoclonal antibodies techniques, fermentation techniques and biocatalyse techniques (Kuusi 1991).

A developer community includes not only producers which use the new technology but also the buyers and users of their products. It includes also the developers and educators of scientific bases of the technology and representatives of e.g. public authorities, organizations of consumers and labor unions, who promote the use of the technological paradigm. It is important to notice that also active critics of the technology belong to its developer community. A technology has community sometimes a clear structure of interaction and decision making. It has often an active or influential core and a passive or powerless periphery.

Different Types of Experts in Future Generic Technologies

The best experts of a generic technology are typically active participants in a worldwide developer community. The worldwide developer community consists further of national developer communities interacting with each other. Interaction networks of members of a developer community are partly international and partly national or even local. Nelson (1993) proposes that just as the idea of national innovation systems has become widely accepted, technological communities have become more international than ever before.

If one likes to make realistic evaluations of the future possibilities of a generic technology, the scope of a developer community or a technology community should not be too narrowly defined. Nelson (1993) mentions as major institutional actors of a technology community firms, industrial research laboratories, research universities, government laboratories, training institutions and financial institutions. I think that this list of institutions is too short. The regulative activities of civil servants and citizen organizations (political parties, Greenpeace etc..) are very important.

I think it is useful to look at four different basic types of experts in developer communities of generic technologies (Kuusi 1994):

- scientists in basic research
- scientists and decision makers in business organizations
- scientists in public organizations and public authorities in the areas relevant to the development of generic technologies
- scientists and other experts in citizen organizations (e.g. political parties, consumer organizations, environmental organizations, trade unions)

These groups of experts have different expertise in future technologies and different role expectations concerning delivery of their knowledge. If one likes to use a panel of experts (e.g. in a Delphi study) to assess the possible futures of some generic technology, it is important to realize the different expertise and interests of these groups.

The relevant differences between the expert groups is summarized below based mostly on experiences in three Delphi-studies concerning the future of information services, the new biotechnology and new material technology (Kuusi 1987,1991,1994) .

The best expertise of **the scientists in basic research** concerns general technical possibilities or recently found laws or invariants of nature. Typically they are short of expertise in production costs or potential market demands of possible new products.

The scientists typically see the transferring of their knowledge as a kind of mission and may adopt an attitude to knowledge as an article for barter (information in exchange for other information) only for unique knowledge (compare Zucker et al., 1995). A genuine scientist seldom interprets his knowledge as merchandise.

The invariants of the future, which a scientist in basic research presents, are usually quite well verified. The scientist also usually presents without a separate request the reservations which are related to his knowledge.

A scientist in basic research is a good critical evaluator of scientific information presented by other experts. He or she is often an excellent uncoverer of another expert's purposeful hiding or misrepresentation.

The scientists in basic research can be divided into two types. The first type is careful to present only an invariance which has been justified extremely well. The information transmitted by this type of scientist is trustworthy but typically its scope is narrow. The second type is directed at the building of syntheses and theoretic generalizations. He is capable of presenting large syntheses but he may hide facts which do not validate his conclusions. This kind of a scientist emphasizes willingly the development which is connected with his favorite theory but he or she may ignore the possibility of another kind of technical development.

A scientist in basic research sometimes has conflicting roles, e.g. when he or she is engaged not only a scientific work but also in business or as an representative of some citizen organization. Even a "pure" scientist may experience a role conflict, because basic research and commercial applications are nowadays often closely interconnected. As Nelson (1993) has noted the claim that new commercial technologies have given rise to new sciences is at least as true as the other way around.

The role expectations of **scientists and decision makers in business organizations** are quite different than those of scientists in basic research.

The representatives of business organizations in technology foresight panels interpret their expertise as merchandise in a generic technology and especially their expertise in developing plans of their company. If the expertise has an economic value, it is delivered only in barter (information in exchange for other information) or against another type of compensation. If a firm expert does not get adequate compensation, he or she typically delivers information in a very general form or sometimes even in a biased form.

The assessment of "adequate compensation" is in no way a simple thing. The sharing of information about realized and potential applications of a generic technology has both negative and positive monetary value to a firm. A negative value is for example, that real and potential competitors get information about technical achievements or production ideas. On the other hand, the sharing of information has also positive economic value: those who get information may be potential customers or partners or their reactions may anticipate how a product will be accepted in a market. The weights of positive and negative values in information sharing differ e.g. when

- the shared information concerns technical solutions under development and the solutions have not been protected by patents or by other procedures;
- the shared information concerns the company's products which are just coming to a market or which are already in a market or
- the shared information concerns distant applications of a generic technology.

In the first case an open distribution of information is unlikely. In the second case a possible solution is to deliver information openly but only as much as is needed to convince the customers. If for example the quality of a product can be clearly stated without hints to the manufacturing process, an attempt may be made to retain the manufacturing process as a business secret. On the other hand, positive messages concerning e.g. environmental or employment impacts of the production process may improve the company's image and its market position.

In the third case experts in enterprises are often ready to behave like scientists in basic research. Some experts, however, consider that a contemplation of distant uses of a generic technology is useless and has only a tiny economic value. Some other think that the free exchange of information is a useful way to find new solutions. Beside that they may think that it is an intellectually exciting enterprise.

In an expert panel of a future generic technology a company representative is usually a good evaluator of the economic realism of other panelists. He is especially good in pointing out the weak points in the arguments of competitors of his or her firm.

Scientific experts in developing tasks in companies experience sometimes difficult role conflicts. In their role as scientists they have an interest to spread information about their findings and their favorite theories. In real interview situations the role conflict is expressed by statements like "I am talking now about confidential matters, do not mention this in your report". A similar type of problem is experienced by business experts whose ethical convictions forbid lying.

The third basic group of experts are **civil servants**. They have special role expectations as members of expert panels of future generic technologies, too:

1. A civil servant considers as his duty to tell about existing regulations and the reasons for the regulations.

2. The civil servants are usually ready to tell about regulation or infrastructure alternatives extensively already at the early preparation phase. They like to be aware of possible effects and reactions of different possibilities.

3. Civil servants can in many ways contribute to the diffusion of a generic technology. They transmit information and ideas to political decision-makers. They have often direct influence on infrastructure decisions. Some decide on loans and supports to the applications of technologies.

4. The civil servants are often good arbitrators of interests because they have often extensive contact networks in a developer community and because they are often considered to be more neutral than other expert groups. Sometimes the experts in the banking sector have got a similar role of arbitrator.

The fourth group of experts are the **scientists and other experts in citizen organizations.**

A representative of a citizen organization typically argues that he or she has a scientist-like open attitude to distribution of information. However, he may have a subconscious or sometimes conscious aim to transmit mainly the information supporting the aims and ideas of the organization represented by him. His knowledge about the invariants of nature affecting in the future is often defective but he is usually willing to learn and likes to find good syntheses.

A representative of a citizen organization is often an active ethical evaluator of alternative futures. He is often eager to estimate ethical validity of the arguments of representatives of other groups. He reacts often intensively against the breakers of generally approved norms e. g. against dishonesty or narrow pursue of own interests.

A representative of a citizen organization may be uncritical in comparison with the representatives of other expert groups. His or her ideas may, however, represent the way of thinking e.g. of a powerful political party.

Phases of an Innovation Process and Expert Foresight of Future Innovations

A practical way to conceptualize an innovation process is to describe its phases through the market position or the turnover of the products resulting from the process. It is reasonable to assume that the development is S-shaped (a form of a logistic curve). The reason for this form is that a technology starts slowly and many impediments must initially be overcome. In the next phase the technology advances rapidly for a period and then slows as the easy improvements have been "mined" (Rip 1995).

An innovation process seldom leads to one product but to a series of products or innovations resembling each other. Innovation processes typically have following four or five phases.

1) **A vague idea of possible innovations.** Noticing of inventions on which a product design can be based and a vague idea of possible uses of products (in the science push model) or a specific idea of possible uses of a new product and a vague idea of inventions, which may realize this type of product (the demand pull model).

2) **Designing the first marketable products** which are directed to a limited group of customers.

3) **Broadening the variety and improving the products.** Incremental inventions improving the first marketable products and broadening the variety of products. This widens the group of customers. The building of an infrastructure, which economizes the use of the product.

4) **Finding a "dominant design"** or a final innovation, which can be improved only marginally

5) **Emerging a totally new design**, which is based on different inventions.

A practical way to make technology foresight studies is to ask experts to mention promising innovation processes which have already started or which are planned to start. A good focus of discussion are the timing of different phases in an innovation process and the turnovers of different products resulting from the innovation process.

The arguments which are relevant for the timing of phases and the turnovers of products concern often the barriers of an innovation process. The transition from one phase to the next requires the overcoming of specific barriers. For example Abernathy and Utterback (1978) have proposed that units in the second or in the third phase ("fluid units") view as barriers any factors that impede product standardization and market aggregation. The firms in the next phase, on the other hand, tend to rank uncertainty over government regulation or vulnerability of existing investments as more important disruptive factors.

A fundamental problem in a technology foresight study is that the expertise and interests of experts vary concerning different phases of the innovation process.

Most qualified experts of **the first phase** are, on the one hand, scientists who know promising new scientific laws, invariants or generic inventions and, on the other hand, experts who know the changing needs or wants of customers. They are often decision makers in firms or experts of consumer needs and tastes.

In **the second phase** science push and demand pull approaches differ concerning the targeted customers and first products designed (e.g. Burgelman - Sayles 1986). In the science push approach the first product is typically based on something that directly follows from promising inventions or from a promising generic technology. If in the innovating firm there is a "champion" or "true believer" of a new generic technology, he or she is very eager to make this type of application. In a technology foresight panel "true believers" are often scientists working in firms or researchers who make applications of some generic technology for firms. In Finland they often work e.g. in the Technical Research Centre of Finland.

Because "true believers" typically see the economic possibilities of their applications as being very promising, their readiness to tell technical details to other experts depends very much on the development phase of the product. If the product is not in the market, its "champions" are very reluctant to speak of it in specific terms. When the product is in the market and protected by patents, "champions" of the product on the other hand are often very eager to speak about it.

According to Burgelman and Sayles (1986) the demand pull approach typically leads to a first product that fulfills an easily identified and safe demand but with minor potential. For this type of decision maker what is interesting is not the technical solution of the product, but rather the fact that the product works in the intended use better than earlier products. Although an demand pull-oriented expert in a firm very well understands the "economic relevance of silence" before the phase of marketing of some product, he may be ready to tell in general terms which type of technology is used in the design of a planned product.

If one likes to use the first products as weak signals of the future use of some generic technology, it is useful to evaluate the "technology push" and "demand pull" orientation of the producers. As Burgelman and Sayles (1986) have noticed, it is reasonable to hypothesize that both orientations are biased in different ways. The price of technological championship is that the first product often addresses only the needs of an atypical user and the product is locked into one technical solution. On the other hand, if a demand pull-oriented decision maker meets difficulties in meeting an identified demand with the aimed generic technology, he easily refuses the technology as impractical.

An interesting information source regarding the future use of a generic technology is a frustrated "true believer". He may be a scientist who has worked in a firm which has to his or her mind too easily refused a generic technology. This type of person is often ready to discuss very openly about the possibilities and difficulties of the new technology. Of course it is crucial to put other experts to evaluate his comments.

In the phase of first applications of a generic technology public technology administration has an important role. The public support of firms is often very much focused on this phase of the applied research. In Finland such organizations as Technology Development Centre in Finland (TEKES) and Technical Research Centre of Finland (VTT) see as their role promoting applications of new generic technologies and encouraging firms in innovation processes.

The public authorities often have a crucial role in this phase. For example in the case of first products made by using gene manipulation the safety considerations of public authorities have delayed the entry of technically ready products to the market for several years.

In **the third phase** of an innovation process, feedback from customers is decisive. In many product areas consumers, for example, want to continue their old habits with new products. This is relevant especially for food, as e.g. Pantzar (1992) shows to be the case in the competition between butter and margarine in Finland. Workers of consumer organizations are often good experts regarding potential reactions of consumers to new products and consumer organizations often actively enhance or criticize the use of a new product. The critique may concern, for example, the environmental effects of a product or its production technology. Sometimes consumer organizations have even succeeded to forbid a product which public authorities have been ready to accept.

In using first products as indicators of the future use of a generic technology one has to keep in mind that the firms which have made first marketable products are not automatically the same which succeed in the incremental improvements of major basic innovations. Transistor radios, color televisions, videocassette recorders and numerically controlled machine tools are just a few examples of products now dominated by companies in other countries, even though the crucial enabling technological advances were first made in the United States (Dertouzos et al., 1990 cited from Pine II 1993).

The achievements of a country in large production based on a new generic technology or new technological paradigm depend very much on the physical, institutional and intellectual infrastructure of the country.

Sometimes an enabling infrastructure is very specific. For example, in the case of mobile phones an important prerequisite for the success of Swedish Ericsson and Finnish Nokia was the Nordic Mobile Telephone (NMT) standard taken in the use in 1981-1982. The new pan - European GSM (Global System for Mobile Communications) is based much on this Nordic standard. On the other hand, the success required beside the favorable infrastructure that both firms had already in an early phase experimented with digital technology.

Sometimes enabling infrastructure requires fundamental changes in most institutions of a society. Joseph Pine II (1993) explains the present achievements of Japan in mass production with a new production paradigm, mass customization. The structural prerequisites to behave according to the new production paradigm can be seen as enabling the use of new information technology. Instead of traditional mass production, which is based on stable demand, the new paradigm is based on fragmented demand. Another key feature of mass customization is the production of low-cost, high quality customized goods and services to heterogeneous niches. Instead of long development and product life cycles of traditional mass production the new production paradigm is supposed to be based on short product development and product life cycles.

Typically there are many possible choices concerning an enabling infrastructure. The forecasts concerning future technologies are conditioned by the choice of an infrastructure. An important reason for making a public technology forecast is often the decision concerning enabling infrastructures. For example, in my study of the future materials (Kuusi 1994) perhaps the most interesting result was the three possible infrastructure strategies for the sustainable use of materials and energy. The choice of infrastructures often determines the most profitable ways to use a generic technology. The best informed persons concerning this choice are often the representatives of public authorities.

The construction of an enabling infrastructure is directly connected to the shifting to **the forth phase** in a product cycle. In this phase few product designs get dominant roles in a market. The dominant design may concern only some features of a product as the MS-DOS standard in personal computers. At least in the old times of mass production a dominant design had sometimes been a specific product as the T-Ford before the Second World War.

Conclusions

A key concept of this article is the developer community of a generic technology. Technology foresight based on expert knowledge is very much a "self-reflection activity" of a developer community. Technology foresight is based on a critical examination and an amplification of that competence, which a developer community already has. Typically the successfulness of a technology foresight enterprise depends on the very same developer community from which the expert knowledge has been collected. If this community cannot utilize the results, they are useless.

The concept of developer community is analogous to the concept of "scientific language community" used by late Thomas Kuhn (Kuhn 1991). According to Kuhn strong evidence (e.g. an argument concerning the future) for one community, need not be evidence for the other. Like a language community, a technology community has a core and a periphery. Actors on the periphery have to accept the lexicon of the community or "rules of the game" as such in order to have an influence on the behavior of the community. On the other hand, those in the core are capable of changing the rules of the game, e.g. the acceptable arguments concerning the future.

The scope or the limits of a developer community change continuously. A technology foresight study can broaden the group of people who belong to the community. It can also have an impact on the structure of the community. Some persons or institutions which earlier were on the periphery may move to the core of the community.

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CREATING AND COMMUNICATING TECHNOLOGY FORESIGHT - Differences between various types of technology study

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Introduction

The competitiveness of industries and economies is largely determined by the technologies in use. Depending on the context, being at the front line of technological development can be seen as a competitive advantage of a businesses or a nation (Porter, 1985, 1990). At the same time, however, the adoption of new technologies may generate essential structural changes in industrial and societal environments. Consequently, where the individual-, organization- or nation-level focus is on survival or on more ambitious targets, considerable effort and sacrifice are often needed in adapting to the changing world. Anticipation of technological development is thus a key to discovering future opportunities and threats, as well as a prerequisite for mitigating the often painful adaptation processes required by the structural changes.

We can thus conclude that technology foresight - or some kind of information about future technologies - is needed to prepare people and organizations for the world of tomorrow. At the society level this information is needed for political decision making: proper infrastructures for businesses and societies based on the new technologies must be created, educational systems must be developed to correspond with the future needs, and so on. At the company or organization level, technology foresight is needed for successful business strategies, to ensure the long-term competitiveness of the company or organization in question. Even at the individual level, citizens' personal decision making could benefit from information on future technologies: in a rapidly changing world it is not straightforward to acquire proper competencies and conditions for meaningful professional and personal development merely on the basis of former experiences.

Although we may agree that technology foresight would be extremely valuable for planners and decision makers at various levels of society, it is not easy to answer the central question, how to contribute to this foresight. A commonly accepted view today is that we cannot accurately predict long-term economic, societal and technological developments. This view is partly based on empirical studies (e.g. Ascher, 1978; Daub, 1987; Schnaars, 1989), and partly on new theoretical insight into the behaviour of dynamic systems (see e.g. Gleick, 1987; Simon, 1990; Silverberg & Verspagen, 1996/Nelson, 1995). Still, it can be argued that there always exists knowledge on the basis of which we can conclude something about the future. In particular,

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well-informed experts and active citizen groups may possess valuable information about issues relevant to future technological developments. If these informants are given an opportunity to communicate with each other, the various pieces of information can be integrated into increased technology foresight (Vapaavuori, 1993; Kuusi, 1993, 1996).

It is clear that the depth and quality of the information considered affects the validity of the resulting visions of future technological developments. It should, however, be noted that it is not just the information possessed by the experts and other informants that affects the outcomes of the process. The process of converting existing pieces of information into increased technology foresight is likely to be complicated by communicational and situation-specific problems as well: various expert groups typically speak different languages, and their interest in releasing and sharing their knowledge depends on the context (Kuusi, 1996). The contextual factors that affect the informants' behaviour during the integration process may, in turn, lead to significant differences in the resulting technology foresight and its potential influence on planning and decision making.

In order to facilitate the creation and communication of insightful technology visions, we thus need to pay some attention to organizational conditions in the various types of future study. This paper presents a tentative typology for technology studies which illuminates the varying organizational conditions and the ways in which these may affect the resulting information. The emphasis in the following is on the process of foresight creation. The potential influence paths of the different types of technology study are briefly discussed in the concluding section.

Who Prepares Technology Forecasts, for Whom and for What Purpose?

During the past few decades, several attempts have been made to forecast future technological developments. Some of the studies have covered a wide range of technologies (like Gordon & Helmer, 1964[1], IFT, 1988; Burton & Cheney, 1991; BMFT, 1993), others have been more focused, concentrating on the technological development in a specific sector of industry (see e.g. Kuusi, 1987, 1991, 1994; Leebaert, 1991). The time horizons of the studies have varied typically from 10 to 50 years. Somewhat shorter time horizons appear in company-specific studies and in national-level competitiveness comparisons. Longer time horizons can, in turn, be found in science fiction-type future studies.

Various qualitative and quantitative approaches have been developed for producing technology forecasts. Some efforts have also been made to assess the quality of the forecasts by examining their accuracy, or their underlying assumptions and methodology (see e.g. Ascher, 1978; Schnaars, 1989). Nevertheless, it is difficult to distinguish clear normative guidelines for technology forecasting. This is partly because little attention has been paid to the varying organizational conditions in the

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1 The classic study has been referred to in a number of research reports, see e.g. Mannermaa, 1991.

different types of technology study. Even if the information is synthesized with the help of formal processes and methods, the conditions of information processing and communication vary depending on who orders the study, the objectives and the intended users. These factors affect both the process of forecasting and the messages generated (Eerola, 1990a). What follows is a closer look at the various types of technology study to promote better understanding of these differences. The content of the following discussion is illustrated in Figure 1[2].

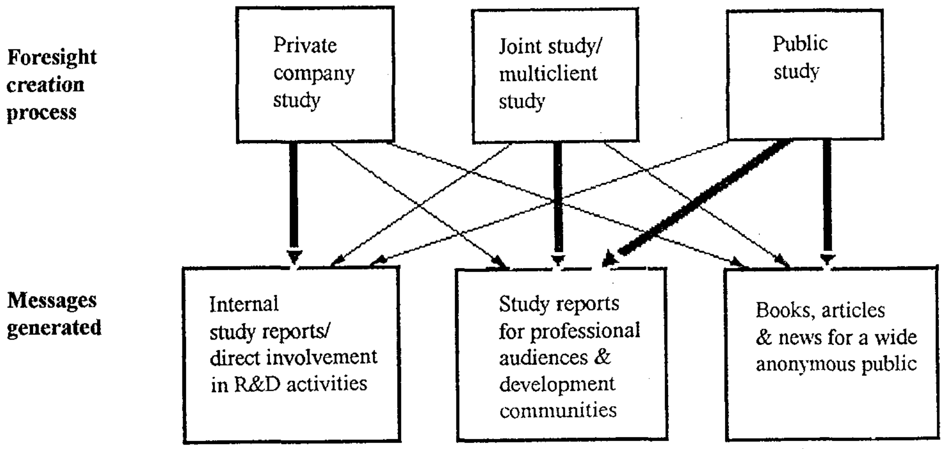

Figure 1. Various types of technology study: foresight creation processes and messages examined

A rough categorization shows three different types of technology study: 1) *private,* primarily serving individual companies or organizations, 2) *joint* or *multiclient,* serving wider business communities that share some common interests and 3) *public,* intended to serve the entire society or some important parts of it. Private studies refer to technology studies that are carried out confidentially by companies' own experts or others on trust (consultants, researchers, etc.), although external informants may still be widely used to provide input. Joint studies mean technology studies that are genuinely carried out as joint projects by a number of organizations who share the costs of the process and the resulting information. Multiclient studies, on the other hand, refer to common technology studies that are delegated to consultants or research institutes that, in turn, sell the resulting reports to those sharing the interest. (The initiative for a multiclient study may come from those preparing or buying it, and additional informants may be used to provide input.) Finally, public studies refer here to studies by academic research groups, or those initiated by governmental and political organs (in which case a wide-base working group is typically built up for the purpose). Even science fiction-type future studies can be put into this category of technology studies, if they contribute new insights and follow the laws of nature. The

[2] The discussion in this paper follows the outlines of an earlier study on consultants' market forecasting services (Eerola, 1990a). The concepts and categories are here modified to correspond to the present context.

common feature of all public studies is, however, that the information generated is available to a wide audience for a relatively small charge (or sometimes even free of charge).

As illustrated in Figure 1, each type of technology study may result in several different types of output message. The content and form of the messages generated depend on the type of study, as described in the following. The objectives of the study and its intended target groups further determine which pieces of information are included in the intermediate and final reports.

Private technology forecasts can be produced in the context of companies' R & D projects that focus on new technological innovations, or they may be needed for discussing and evaluating the companies' strategies on a more general level. In either case it can be anticipated that the producers and users of the technology forecasts partly overlap and interact at personal level. Furthermore, they have a shared interest in promoting and contributing to the company's successful development. This ensures that even in-house business secrets can be discussed in an atmosphere of trust - loyalty to the company is expected, leaking is a business crime.

The most important results of private technology studies - information about new innovations and important R&D-projects - are typically internal and confidential, but it may still be advantageous for the company to release some of this to a wider public (in order to strengthen the company's argumentation power when negotiating financial arrangements, and to create a market for the new-technology products).

Joint studies and multiclient studies are intended to serve the specific industries and interest groups who share the costs of the process. Making joint efforts in technology forecasting is one way of cutting down the costs that individual companies and organizations incur for the process and its results. Joint efforts also make it possible to utilize somewhat broader expertise for the forecasting task: the expertise of the participating companies and organizations can be combined reasonably easily since the participants of the process share some common reference frames and interests. Company secrets may, however, restrict the informants' input and openness during the forecasting process to some extent. Because only a small fraction of the users of a joint or multiclient study can, in fact, participate in preparing it, the participants of the process 'filter' the generated information down to the remaining users. The end-users of multiclient studies are a more or less anonymous audience to the information producers.

Although joint and multiclient studies result in messages that are generated primarily for the business community who ordered and/or initiated them, there may be economic and political reasons why some of the results should be marketed to a wider public. Even more specific messages for the participants' own organizations may be generated as a side product: those involved in the forecasting process may discover information that could be useful for their own businesses, although this specific information may not be included in the official study reports.

The basis and the purposes of **public technology studies** vary. Academic technology forecasting and futures research is usually disciplinary work carried out by individual researchers or research groups, whereas in science fiction literature the imagination of the author is allowed to play an important role. The common feature is, however, that no direct links between information production and real decision-making situations are assumed: academic research is reported in scientific articles, books and conference papers that primarily reach the academic audience, and science fiction literature is mainly read as entertainment by individual citizens. It should, however, be noted that academic and science fiction writing can be used as basic material for more specific purposes: their authors and readers may act as informants for other types of technology study, generating important messages for planners and decision makers at various levels of society.

Another important group of public technology studies comprises studies initiated by governmental or political organs. A wide-base study group is usually needed to ensure that the interests of those concerned are represented. In practice, the informants for this type of technology study may thus come from a wide range of different organizations (universities, research institutes, business organizations and active citizen groups), whereas the coordination task is often delegated to a specific project group. As the intended primary users of the study are those involved in public planning and political decision making, as well as the key actors in the development communities concerned, the producers of the information are mainly people other than the primary users.

The central messages of a technology study initiated by governmental or political organs are often presented to planners and decision makers in special planning seminars, backed up by written reports. The information is intended to contribute to the decision context in question, or just to stimulate planners' and decision makers' future oriented thinking. A further requirement is that the central results are communicated to important citizen groups in order to ensure that those concerned have the opportunity to participate in the democratic processes of decision making. This means, at least, that some essential outcomes of the forecasting process are communicated to a wide audience free of charge or for a modest fee (in newspapers and booklets, at public seminars, through the electronic media).

The above classification of technology foresight studies into three distinct categories is of course somewhat ideal: in reality, studies exist that are combinations and/or variations of the three ideal types discussed above. By explicitly examining these, however, we can effectively illustrate how the conditions of information processing and communication can vary considerably depending on the context of the technology study. The differences so far discussed are summarized in Table 1.

Table 1 Creating technology foresight: Central actors and objectives in the three different types of technology study

Type of technology study	Private company study	Joint study/ Multiclient study	Public study,
Orderer	Company management	A group of companies & organizations sharing a common interest	Society, citizens Public authorities
			Academic community
Producers of technology foresight	In-house experts & others on trust	Inter-organizational task force/authorized project group with a common reference frame	Wide-base task force/ authorized project group with multiple reference frames
			Academic researchers (Science fiction authors)
Primary users of the results	Company management and its R&D groups	Companies & org. ordering the study and sharing its costs	Public planners, advisors & politicians
			Scientists& technologists Citizens
Primary objectives of the study	Supporting company's strategy formation and innovation activities	Strengthening industrial competitiveness	Supporting public planning & political decision making
		Coordinating the strategies of the industry/ efforts of the development community	Coordinating the efforts of the development community
			Stimulating future-oriented thinking

Integration of Expert Information - Organizational Dependencies

Various procedures and formal methods have been developed for integrating information for future studies and forecasts. Among these are delphi panels, morphological tables, cross-impact analysis, life-cycle analysis, statistical methods for analysing time series and cross-sectional data, and simulation methods for analysing dynamic systems. As there are numerous books describing forecasting methodologies as such (see e.g. Armstrong, 1985; Turoff & Linstone, 1975; Mäenpää, 1977; Jones & Twiss, 1978; Makridakis & Wheelwright, 1982; Vapaavuori, 1993), the traditional methodology discussion will be excluded in this paper. The focus is rather on the organizational conditions under which technology foresight is generated.

Even if formal procedures and the most sophisticated techniques are used, information production and use are essentially social processes where various people communicate with each other face-to-face, via filed information or via various electronic media and telecommunication devices (Short et al, 1976; Christie, 1981). This is an underlying assumption in the following discussion, covering the organizational dependencies in the three ideal types of technology study. In particular, four central issues are paid attention to: the resources available for the study, the possibilities to influence the study content and timing, the learning opportunities during and between the studies, and the information users' and producers' commitment to the various types of technology study.

The first category of technology study was labelled **private company studies**. The scope in this type of technology forecasting is typically quite narrow, reflecting the specific business area of the company. The nature of the industry and its R&D projects determine, in turn, the time horizons of interest. Although the end users of the information can largely determine which specific issues and topics should be considered during the process, the resources available - money, time and people - may place some fundamental limits on the breadth and depth of the study. On the other hand, in-depth discussion may be encouraged by truly confidential processes in an atmosphere of trust.

If the creation of technology foresight is an integrated part of a company's R&D-activities, the timing and progression of the process are bound to the current state of these activities. The company management may, however, also initiate somewhat wider technology studies to support the company's strategy formation in some crucial situations. In either case, even the intermediate results of the technology studies are usually available to the end users of the information, making it possible for them to give feedback for the remaining part of the work (the producers and users of information are overlapping groups with personal-level interaction). Learning during the process can thus be directed by the information users.

Since the company itself is responsible for the total costs, it can be assumed that the effort and resources an individual company is willing to devote to a new technology study depend on the expected utility of the increased insight in a specific context (importance of the project, gravity of the situation, the company's unique competencies that can be utilized for the purpose). On the other hand, the company's commitment to 'old favourite topics' may also be influenced by the sacrifices so far made: escalating commitment to a chosen course of action has been observed in descriptive studies on organizational decision making (see e.g. Staw, 1976). Although the majority of those participating in the process can be expected to share the interests of the company (at least to some extent), their commitment to specific technology studies may vary depending on their own professional and personal interests.

Joint studies and multiclient studies are produced to serve larger business communities or entire sectors of industry. Although the scope is usually wider than in private company-specific studies, the issues and topics selected for further examination are expected to reflect the current interests of the business community (or the sector of industry) that initiated the study. The same is true for the time horizons considered. The topics, issues and time horizons to be examined in a specific study, are largely determined by those initiating it (usually a few representatives of the primary users). Those participating in the process may perhaps be able to modify the initial suggestions, but for the majority of the information users, the contents are predetermined or taken for granted. On the other hand, more extensive resources may allow considerable breadth and depth. However, the protection of business secrets may hinder deeper drilling in crucial issues and details.

The timing of joint and multiclient studies may be determined by some acute situational factors within the business community or industry sector in question. Joint studies are usually unique in nature, whereas multiclient technology studies may also be produced on a regular basis to keep the ordering community up-to-date with technological developments[3]. In either case, the intermediate results of the study can be utilized primarily by those participating the process, whereas the majority of the primary information users are expected to be content with the final study report. Feedback from the information users during the study is thus limited to those who participate in the foresight creation process. Learning during a particular technology study is thus mainly based on the information producers' accumulating experience and knowledge about other technology studies. In repetitive forecasting, user feedback on final study results can, however, direct forthcoming forecasting efforts. Since new studies are often initiated and/or ordered on the basis of information users' evaluation of the usefulness of previous studies, the primary users' experience may be crucial in the long run.

The results of joint and multiclient studies are available to companies and organizations who share the costs. In practice, this means that extensive information is received against a considerable fee. Someone in the company is thus likely to be expected to pay some attention to the information acquired. On the other hand, the psychological distance between the information production and use (Christie, 1981) may decrease the end-users' commitment to the specific information. On the other hand, after long-lasting intensive work, the project group itself may be extremely committed to fulfilling the task and to promoting its results.

As described in the previous section, **public technology studies** may be produced to serve public planning and political decision making, to coordinate the efforts of technology development, or just to increase the general awareness of technological change. The varying contexts of public technology studies are illustrated here in discussion of the organizational conditions of academic technology forecasting and technology studies initiated by governmental and political organs. The reader may, however, extend the discussion to science fiction literature as well.

<u>Academic research</u> on future technologies is mainly directed by the interests of individual researchers, who have great freedom in determining study content. The financing institutes may, however, indirectly affect the issues and topics considered, as well as the timing of the study. Although people in the business sector may provide valuable input, it may be somewhat difficult to motivate them to contribute in other ways. This is because the links between academic research, and planning and decision-making are usually indirect and diffuse, making it difficult to determine the

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[3] For instance, in Japan this type of technology study is produced at 4-5-year intervals, with some minor modifications in content.

real benefits of the study. Feedback during and after the foresight creation process is thus to be expected mainly from academic research fellows. This, in turn, facilitates learning that serves the scientific community in the first place. As a consequence, commitment to study results may be restricted to academic circles.

On the other hand, governmental and political organs might be expected to initiate technology studies when they think that society (planners, decision makers and ordinary citizens) needs assistance in preparing for the future. The scope and time horizons of this type of technology study are usually relatively wide, since society-level issues are concerned. The issues and topics considered are determined on the basis of general-level suggestions provided by the initiators of the project. The co-ordinators of the study may, however, revise and complete the intended contents on the basis of expert opinions during the process. Since the study is intended to serve the entire society (or some relatively large subgroups of it), and participants in the process have varying backgrounds, a great variety of relatively general-level issues can be expected to be selected for further examination. Participants' varying reference frames and interests, as well as the protection of business secrets, may considerably complicate the process. The final breadth and depth of the information produced is thus not merely a function of the public resources available for the purpose. Skillful coordination and insightful selection of informants are needed to overcome the pitfalls of interdisciplinary and cross-sectoral information exchange.

Societal and political processes typically define the timing of this type of technology study. Those involved in public planning and political decision making may see some intermediate results already during the process if they need them for their immediate work and decision making. Selective intermediate reporting in the public media may also be needed for political reasons. Some feedback during the forecasting process may thus be received from informed planners and politicians, as well as from other active citizens. Feedback from a wider audience comes usually after publication. If the project is non-recurrent, and has been carried out by a temporary project group/task force, this feedback cannot, however, directly influence the subsequent technology studies. On the other hand, the participants and coordinators of the study can transfer their own experience-based learning and accumulated knowledge to other relevant contexts.

Although the resources offered for a public study may be considerable, the psychological distance of the ultimate sources of the funding may diminish society's collective commitment to the study. The commitment of those involved in public planning and political decision making may, in turn, depend on how well the information fits into the 'planning paradigm' in use: if planning is not done in an evolutionary spirit (see e.g. Loikkanen, 1996; Pantzar, 1996), technology forecasts that reduce perceived uncertainties are likely to be preferred to foresight that increases the spectrum of options. An extensive technology study may, however, be a unique experience for the coordinating group (it gives an opportunity to face new challenges, to extend personal contact networks, etc.), thus increasing commitment to the work. The commitment of a wide range of informants may, in turn, considerably vary depending on their roles in the process and their situation-specific interests. (It is, however, likely that those with the highest level of commitment will naturally be most deeply involved in the process of technology foresight creation.)

The above discussion took up some contextual issues that may affect the creation of technology foresight. In reality, there may be other issues of equal importance. The foregoing discussion should thus be understood primarily as an attempt to illustrate the importance of contextual analyses and organizational issues, not as exhaustive treatment of the topic.

Generating Technology Foresight - Modes of Knowledge Creation

As described in the previous section the organizational conditions for integrating the knowledge of experts and other informants differ depending on the type and context of the study in question. Consequently, the resulting synthesis may take different forms. Yet, if we strive for increased technology foresight, it is not enough just to carefully combine the information provided by experts and other informants. The ultimate aim is to create essentially new knowledge during the process. Various ways of generating new knowledge are discussed in this section.

During the past decade, researchers in the field of organization and management have shifted their attention from information processing and problem solving to knowledge creation and issue interpretation. Recent studies have focused on the various modes and dynamics of knowledge creation (Nonaka, 1994; Nonaka et al, 1994; Hedlund, 1994; Spender, 1994), the effects of attention and issue framing in managerial decision making (Dutton et al, 1989, 1993; March & Shapira, 1992; Shapira, 1994), and the actual ways in which formal analyses and expert information are used (Daub, 1987; Feldman, 1989; Langley, 1989, 1990, 1995; Eerola, 1990b, 1995). Although these studies have been conducted in contexts slightly different from technology forecasting, they bring up interesting issues that are important for the conceptual analysis under discussion as well. In this section, Nonaka's insightful article (Nonaka, 1994) will be applied to the present context. The other studies contribute, in turn, to the concluding section.

In general, it can be said that knowledge is created and organized on the basis of received information. This information doesn't, however, determine the contents of the resulting knowledge, since knowledge creation processes are firmly anchored in the commitment and beliefs of the information receiver[4]. Furthermore, in most practical contexts, knowledge that can be expressed in words and numbers only represents a small fragment of relevant knowledge: most people - among them highly educated experts - frequently experience the problem of knowing more than they are able to tell. In the context of technology studies we can, in fact, speak about two different types of knowledge: *explicit knowledge* of emerging technologies that is transmittable in

[4] The semantic aspect of information that focuses on conveyed meaning is more relevant here than the syntactic aspect discussed e.g. by Shannon & Weaver. Furthermore, knowledge is understood here as a dynamic human process where justified personal beliefs form part of an aspiration for the 'truth' (Nonaka, 1994).

formal, systematic language, and *tacit knowledge* of factors affecting technological development that is hard to formalize and communicate because it is deeply rooted in action, commitment and involvement in a specific context. In addition to relatively concrete things, such as contextual know-how, crafts and skills, even people's images of reality and visions of the future are included in their tacit knowledge (Nonaka, 1994). Various person-specific schemata, paradigms, beliefs and perspectives thus enter the process of knowledge creation in technology studies, no matter how the forecasting processes are formalized and organized .

Traditional studies using an 'information-processing perspective' have mainly focused on the ways in which explicit knowledge can be effectively converted and combined to serve some new purposes. In fact, four different modes of knowledge conversion may be considered of interest in creation of technology foresight: 1) explicit articulation of tacit knowledge ('externalization' in Nonaka's terms), 2) conversion of explicit knowledge to tacit knowledge ('internalization'), 3) conversion of existing tacit knowledge to new tacit knowledge (through 'socialization'), and 4) reorganization of existing explicit knowledge to comprise new explicit knowledge ('combination').

When producing information on future technologies, participant ability and willingness to externalize tacit knowledge may be a key factor in creating essentially new knowledge on important issues. Redundant information in terms of concept development and successive rounds of dialogue in the atmosphere of mutual trust may be a prerequisite. Creation of mutual trust can then be a challenging task, if it does not naturally arise from shared experiences. In this respect, the starting point of 'private studies' within individual companies may have advantages over other types of technology study.

The internalization of explicit knowledge is, in turn, needed in the application of information to a specific context, e.g. when utilizing the results of technology studies for product development or for political decision making. Furthermore, the way in which participants in the study internalize its targets and formal guidelines may have important consequences in terms of the information and knowledge produced. Experimentation and learning by doing facilitate internalization processes, so that the best conditions for the internalization of technology foresight can be provided for those repeatedly and interactively making use of it (R&D experts, and professional planners and decision makers who participate in the production of information).

The key to acquiring tacit knowledge is experience. Although tacit knowledge is often externalized before it is shared with others, it is also possible to transmit some of the tacit knowledge for wider use in other contexts directly through socialization processes. A necessary condition for this, however, is that people share some of their experiences. Without some form of shared experience, it may be extremely difficult for people participating in a technology study (coordinators, experts and other informants) to share in each other's thinking processes. As a consequence the contribution of the study may remain superficial or, alternatively, the results may be biased, because they are based on misconceptions arising from different frames of reference. Thus the real challenge in the different types of technology study is to build up socially skillful 'teams' and 'fields'[5] that exceed the limits of normal organizational and professional boundaries. The broader the scope of the study, the more difficult it may be.

Although the social features of knowledge creation are emphasized in this paper, this does not mean that the combination of existing explicit information through sorting, adding, recategorizing and recontextualizing is not important. Although combination tasks may seem quite straightforward, effective coordination and orderly documentation are needed to successfully complete this type of knowledge creation when extensive amounts of information are being processed. Professional work groups with adequate information-processing tools can be expected to respond best to this need. However, business secrets, as well as difficulties in externalizing tacit knowledge, may restrict the depth and quality of explicit information available for synthesis building.

Thus it can be seen that even technology studies are social processes where people and organization play an important role. Interaction between individuals is of crucial importance, and the way in which various 'communities of interaction' (teams, project groups, task forces) are built, and how their work is managed and organized, can have significant effects on the resulting technology foresight and its potential to trigger changes in the world around. The various modes of knowledge creation in the context of technology foresight are summarized in Table 2.

Table 2. Different modes of knowledge creation in the context of technology foresight (for a general version see Nonaka, 1994)

To: From:	Tacit knowledge of emerging technologies	Explicit knowledge of emerging technologies
Tacit knowledge of emerging technologies and factors affecting technological developments	**Socialization** of knowledge about new technologies	**Externalization** of knowledge about new technologies
Explicit knowledge of emerging technologies and factors affecting technological developments	**Internalization** of information about new technologies	**Combination** of various pieces of information about new technologies

Discussion and Conclusions

Three different types of technology study have been discussed in this paper, focusing on the differences between their objectives, central actors and organizational conditions. It has also been pointed out that each type of study sends some messages to planners and decision-makers at various levels of society - although the aims of the

[5] Examples of natural teams and fields include companies, R&D groups and wider development communities focused on specific technologies.

messages vary, depending on the type of study and the level of decision making. At this point it seems reasonable to add some words of caution to avoid too simplistic an interpretation of the contributions of the various types of study.

When a technology study is initiated, its objectives and primary target groups are usually defined, and its direct instrumental value as input for planning and decision making is likely to be emphasized. These direct links may really be the most influential ones in company-specific studies, but the important contribution in other types of studies may be far more complex: the acknowledged objectives of the study and its actual uses may differ, and the paths of influence are often indirect and diffuse. (This is at least suggested by some recent empirical studies in slightly different contexts; see Feldman, 1989; Eerola, 1990b, 1995). Furthermore, even 'irrational' and casual uses of information may have significant effects on decision outcomes if they trigger changes in decision makers' behaviour. (It has for instance been suggested that managers' risk-taking behaviour depends on reference points and time horizons considered; see March & Shapira, 1987; Shapira, 1994; Eerola, 1995.)

Although it may be difficult to assess the exact effects of increased technology foresight, the various types of technology study may still play an important role in preparing society for the future. If the results of technology studies are used for vision building at society or company level, or as argumentation tools in negotiations and consensus-building processes, the contribution of expert information may be even more influential than when some specific information is used as direct input for product planning. Furthermore, multiclient and public studies are usually easily obtainable to those interested in the topic. Even when the reports are studied just because of curiosity, they may stimulate future-oriented thinking of professional planners and decision-makers, as well as of ordinary citizens. In this way they increase the preparedness for decision making in situations not specified beforehand. Finally, if the actual decisions have already been made, technology studies may be helpful in legitimating the chosen course of action. (Calming down unproductive debates may ease the implementation phase. Yet, it should be kept in mind that all debates are not counterproductive, so that too eager a launching of the 'right visions' may result in loss of important insight, as well as in frustration among important actors.)

Since advanced industrial development is increasingly dependent on the creation and communication of knowledge, it is necessary to pay more attention to the processes by which technology foresight is generated. A shift in thinking about technological innovations is also needed: the processes that lead to new innovations cannot be explained merely in terms of information processing and problem solving. They are rather processes in which various organizations define problems and reference frames, and then actively develop new knowledge for discovering opportunities and solutions that fit into the picture. A firm basis for evaluating this type of technology forecasting may still be lacking. The purpose of this paper was, however, to give some clues for managing and organizing future studies on technological development. At the same time, the powerful role of 'knowledge institutions' in creating visions for the future should be acknowledged.

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THE FORESIGHT AND STANDARDS OF THE TELECOMMUNI-CATIONS REVOLUTION

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Overview

The rapidly evolving technologies of telecommunication are a fascinating sight for the student of innovation, competition and technical change. The future of work, leisure and learning will be shaped by telecommunications. The future of telecommunications has been charted out in recent technology foresight studies. At the same time, standardization efforts in telecommunication technologies reach far into the future. The products envisioned may not become into widespread use until the 2010's. In this paper we compare technology foresight studies with efforts to standardize future technologies.

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The Telecommunications Revolution

Despite all the efforts to predict and standardize the future technologies, most of us were taken by surprise by the rapid development of telecommunications. In mid-1980's, it was not everybody's idea that in ten years we would be sporting digital portable phones as well as receiving and publishing written articles, pictures, sound files, and software via international computer networks.

The present telecommunications revolution - the emergence of international data networks, mobile communications, and multimedia communications - can be likened to the rise of modern newspapers. The printed medium for the masses was made possible by the application of industrial mass-production methods in the printing press. The newspapers made political information widely available for the public - and made democracy possible. In the future, data networks will make world-class intelligence more accessible, threatening the rule of local experts.

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In practice, the telecommunications revolution will, in the short run, only change the way we spend our waking hours. We shall be a little bit more productive in the office as we can collect, process, and distribute information more efficiently. Also, while travelling for business, we shall be able to carry the tools of trade and means of communication with us. At home, we are going spend a little less time watching TV and reading newspapers. Instead, we shall be entertaining and informing ourselves with the help of multimedia data networks for a few minutes in a day in a typical week. While not personally connected to the network, tireless assistant programs will keep seeking and evaluating topical information for our later use.

Industries that will be most affected by the telecommunications revolution are going to be those that rely on information. Employment in the banking sector will be hit the hardest. (See also Lievonen 1995b.) Travel agencies will be in trouble, too, as the customers will be able to book flights and hotel accommodation by themselves. Long-distance learning will cut the demand for local adult education. Local experts will have to specialize further and compete with global geniuses, whose advice will be available in the net, too.

Gradually, the telecommunications revolution will influence almost all aspects of the society. The modern industrial way of life will be surpassed by one that relies on information. Efficient exploitation of energy, raw materials, labour, and transport will not be enough. The rivals making better use of information, research, technology, design, and the arts, will gain a larger market share. Expertise, knowledge, and world-class professional skills will be the source of new products, services, profits, and well-being.

Already today telecommunications is one of the most rapidly growing sectors of modern industrial economies. In 1992 the profits of the 25 largest teleoperators in the OECD countries were U.S. $ 37 billion, that is, more than the combined losses of the countries' automobile industry. (OECD 1995b, pp. 25 and 8.) However, the share of the sector is only about 2 % of the countries' combined GNP. In the European Union member countries the value of telecommunications equipment production will rise to 4,5 % of the GNP by the year 2000. Its value will then exceed the value of automobile production. (Rönkkö 1995.)

Telecommunication systems and consumer products are at a stage of hectic change. As soon as in 1997 most of the new telephone subscriber deals in the world may involve mobile phones. By the year 2000 the number of subscribers using mobile terminals may be 200 million. The similar figure for fixed lines would be 700 million. (Rapeli 1995)

In addition to mobility, multimedia products will increase the demand for telecommunication services. While most companies are now happy with their static, text-based home pages in the Internet, in the near future many will seek the added attention that animation and real-time information will bring. Multimedia services will soon reach mobile customers, too.

Comparing Foresight and Standardization

Technology foresight studies and efforts to define international technical standards share some common features. Both seek to define and influence future technology. In the U.S. the time horizon for technology foresight has usually been 10 to 15 years. In the large technology surveys of Japan and Germany, the time horizon was set at 30 years.

The expected time lag between standardization and finished products rarely exceeds ten years. Usually standardization concerns new technologies that are due to the market over the next few years. The actual time lag between a standard and significant market penetration seems to be inversely related to the importance of the standard. The European standard for digital phones, GSM (now known as the Global System for Mobile communications) was agreed upon already in 1982. The standard was of great significance, but the products for the consumer were widely available only in the early 1990's. The ISDN standard dates from the 1970's, but the application has been really gaining ground just recently in countries such as the U.S., the U.K., Germany and Finland.

Standardization provides exact technical solutions for some clearly defined properties of future products. In telecommunications, standards deal mostly with product interfaces. (Sherif and Sparrel 1992). It is the business of companies and markets to find the best designs for what goes on within the products. Standards ensure that telecommunication products work together, connecting humans or electronic devices over long distances, often beyond national borders, and even continents.

Technology foresight studies aim at no precise product features at all. Foresight studies only provide educated guesses on what might be technically feasible over the next 10 to 30 years. At their best, foresight studies may inspire developers of technology and opinion leaders in international standardization bodies.

Standardization projects attract experts of the highest calibre. Companies readily second their best people for these tasks, as they often involve significant commercial interests. Foresight studies try to solicit the opinions of the best experts, but the detailed, and often sharp, messages from the real visionaries may get blurred, for instance, in the Delphi process.

Foresight studies have usually been *ad hoc* projects. However, in Japan, there already exists a great tradition of future studies. Wide ranging science and technology foresight surveys have been carried out every five years since 1971. In addition to the national studies, many government bodies and individual corporations have performed foresight studies of their own. The total impact of this work has made Japan perhaps the most future-oriented nation in the world.

The foresight process has helped the Japanese to build a unique consensus on what to expect from science and technology. Crucial insights have been gained on newly emerging fields. Many of them have been combinations of technologies such as mechatronics and, more recently, biomimetics. The success of the Japanese tradition has inspired technology foresight studies in Germany, Australia, Great Britain and France. (OECD 1995a, ASTEC 1994.) In the United States, such studies have ordered for by a number of government and independent bodies over the years.

While, rather surprisingly, foresight studies have been carried out within national borders, standardization in telecommunications involves many permanent international organizations. The digital GSM cellular phone standard was defined by the European Telecommunications Standards Institute (ETSI). International Telecommunications Union (ITU), is a governmental organization. Two of its influential committees are ITU-T (e.g. modems) and ITU-R (TV, HDTV and radio). International Electrotechnical Commission (IEC) works closely with International Organization for Standardization (ISO); by itself ISO no jurisdiction on telecommunications. International Maritime Satellite Organization (INMARSAT), too, has been involved in international standardization. (Padgett et.al. 1995.) Now INMARSAT hopes to build a global satellite network for digital portable phones.

The national limitations of the foresight studies have affected the results. The low key approach to international data networks in the fifth Japanese survey is a case in point. In standardization, differences often emerge between American, European and Japanese standards. The resulting incompatibilities hurt both consumers and the most efficient companies. They are a drag on R&D. A lot of patents have been acquired, for instance, in the United States for innovations that deal with conversion between PAL, SECAM, and NTSC colour-tv standards. We shall see more of this in the future, as three standards are underway for the high definition television.

Technology foresight studies have been prepared for the widest, technologically literate, audience. Often their aim, especially in the United States, has been to gain public momentum, and finance, for technologies provided by some specific industries. (But see also Council on Competitiveness 1991 and 1994.) Technology standards are defined for benefit of experts working in companies competing and collaborating in international markets.

In addition to permanent organizations, there are groupings of companies developing standards for specific purposes, often in competition with other alliances. In 1995, a group of 23 companies started efforts to develop standards for data transfer between office equipment. A standard for European digital tv was the aim of a group of more than 80 companies.

Some standardization efforts fail. This is a great embarrassment to the experts and officials involved. The failure of the X.400 e-mail addressing standard was a disappointment for a dedidated group of specialists but a relief to e-mail users. For the first Japanese science and technology foresight survey of 1971, the failure rate was about one third of the propositions expected to be realized by 1991.

Research into Future Standards

The first generation of portable communications (NMT in Northern Europe and AMPS in the U.S.) used analogue means. The second generation was a digital one (GSM in Europe and elsewhere, IS-54 in the U.S.). The cellular mobile systems such as GSM achieve data transfer rates of up to 10 kbit/s - similar to the fax speed of 9600 bit/s.

Currently, the most far reaching telecommunications standardization efforts involve the third generation of portable communications. The aim is to develop a system that would provide global voice and multimedia data services for mobile users.

The recommendations for future standards will be available before the year 2000. Networks and consumer products will be developed in a few years after that. They will be in widespread use probably by the year 2010 - a time span not too different from that used in technology foresight studies.

ITU's global concept is known as the Future Public Land Mobile Telecommunication Systems (FPLMTS). The work is a basis for an ETSI vehicle, the Universal Mobile Telecommunication System (UMTS). (Callendar 1994.) The systems would increase the present mobile data transfer rate 200-fold, to 2 Mbit/s. The high capacity would enable new services for the roaming bank customer, travelling salesman, and even for the driver seeking parking space. A merger of the cellular phone and the lap-top computer is to be expected.

The third generation networks could be superseded by systems that may rival the present-day fixed-line asynchronous transfer mode technology technology (ATM). It is now used to connect, for instance, university supercomputers into a seamless entity. The ATM data transfer rate of 155 Mbit/s is enough to allow simultaneous teamwork over a computer network. You can see your colleague from a distant city, hear his voice, and at the same time, both of you can work together on a computer model of a new product, or study a magnetic resonance image.

Wireless capacity approaching the speed of ATM is being developed, e.g., in Europe. The Advanced Communications Technologies and Services (ACTS) programme of the European Union addresses technical issues that are, as yet, far from becoming standardized or commercialized. A number of trial systems are going to be build. One of them will be a wireless indoor office network that would allow ATM-like video conferencing. Open-air systems of such power are yet to be dreamed of.

Two National Foresight Studies

In this section we shall describe two national technology foresight studies, carried out in Japan and Germany. (NISTEP 1994) The next section will present the surveys' most interesting findings on telecommunication technology. The two surveys are closely related, because the propositions of the Japanese survey, carried out in 1991, were translated directly into German and were used as a basis in a survey in Germany in 1993. (BMFT 1993.)

The reasoning behind the long term technology foresight surveys can be easily understood. The quality of human capital is crucial for the future competitiveness of countries and corporations. In order to see what kinds of human capital will be in greatest demand in the world of 2010, future prospects of technology have to be assessed. Arguably the best way to do that is to consult a large number of experts. The results can then be used in allocating resources for education and research.

Japan has carried out five surveys, the latest in 1991, and the next is due in 1996. For the fifth national survey, 16 fields of science and technology were selected. For each field, forecast propositions were defined by a committee. The number of proposition ranged between 39 and 108 for each field. (NISTEP 1992.)

The topics were evaluated by a large number of experts in a two-round Delphi survey. In Japan, altogether 2385 experts took part in both rounds; in Germany, the number was 857 specialists. The submitted evaluations were taken into account, if the expert indicated high qualifications in the field. For each proposition, the time span needed for its realization was estimated. Among other things, the main hindrances in the way were thought of. They could be related to economics, technology, research or the availability of skilled workforce.

So far, technology foresight studies have adopted a narrow-mindedly positive posture. Only those technological developments that are socially favourable have been considered. Accidents or negative side-effects of new technologies, such as the ecological risks of plant gene technology, have been ruled out by default.

Another problem is that even a large group of experts is unable to take into account rapid revolutionary developments. That is why many of the forecasts of the first Japanese survey were proven untenable by the energy crises of the 1970's and 1980's. Similarly, the propositions of the fifth survey did not fully appreciate the changes that would be soon brought out by new developments in telecommunications and, in particular, international data networks.

Telecommunications in the Foresight Studies

The breakthrough of the Internet started in 1993. The limitations of foresight studies are clearly seen in that the possibility of such a breakthrough evidently was not anticipated by the committees designing propositions for the fifth Japanese survey. Behind such an omission there is the fact that Japan has lagged behind the United States and some European countries in adopting data networks. Such national limitations might be avoided in the future, if international collaboration in technology foresight efforts could be enhanced. (Lievonen 1995a.)

In telecommunications, the greatest attention in the surveys was devoted to HDTV and optical fibres. Japan already is a leader in this field. It already has started operating an

HDTV network based on analogue technology. The United States and Europe are striving for digital technology and hope that it will bring synergy with computer display technology.

Experts in Japan and Germany estimate, that by the year 2001 (2002 in Germany) HDTV should be in widespread use. At the same time, flat HDTV displays should become available. You can hang them on a wall, if you like.

Similarly, in the years 2001-2002, two-way videophones will become into widespread use. Old and disabled people will use them to communicate with support centers.

New telecommunication services will emerge. It will become possible to define personal phone numbers so that you can be reached anywhere in the world. By the years 2002-2003 you should be able to subscribe to automated telecom secretary services. E-mail and database services will be able handle speech and video fluently by the years 2000-2003. Soon after that electronic communication technology will be developed that will enable, for example, the distribution of electronic newspapers. E-mail and other forms of communication technologies will make the home an efficient office.

It will become possible to fetch video files from electronic libraries, which will also contain books and other material. Optical exchanges will be able to serve 10 000 video terminals by the years 2005-2007. Both the Japanese and the German experts think that by the year 2006 more than half of the households will have more than 300 cable-tv channels.

The Lack of Foresight

In the mid-1980's not many of the brightest people in the greatest corporations did not realize what was soon going to happen in telecommunications. Many of the largest corporations in the world were passive in telecommunications R&D, while they were very busy in computers, new materials, and medicines.

A comprehensive source of information on commercial R&D is the data base of the U.S. Patent Office. Patel and Pavitt have compared the patenting activities of the Fortune 500 group of companies for two five-year periods, 1969-1974 and 1985-1990. Surprisingly, the number of large companies receiving U.S. patents in telecommunications fell during the latter period compared to the former.

There were altogether six fields of technology, in which the number of patent-acquiring companies fell. Other unpopular fields included textiles and clothing, wood products and nuclear technology. In computing, medicines, biotechnology and new materials, the number of large corporations acquiring patents in the U.S. increased rapidly.

It seems that the the large corporations were passive in telecommunications research in the period 1985-1990. This was evident in Europe and in the United States, while more Japanese companies were actively patenting telecommunications technologies during the years 1985-1990 than in 1969-1974. (Patel and Pavitt 1994). The rise of the Japanese companies may reflect the more general interest of Japanese companies in acquiring U.S. patents.

The passive patenting record of large U.S. and European companies, if it accurately reflects lack of effort in actual research, may partly explain why newcomers, such as Nokia Corporation of Finland, were able to gain ground rapidly in the early 1990's.

Conclusions

Computer technology, biotechnology, new materials, and some other fields of technology are evolving rapidly and forcing economists and educationalists to consider their long-term impacts on employment and prosperity in various sectors of the economy. In this paper we have discussed attempts to predict and influence developments in one field of technology undergoing revolutionary change, telecommunications.

Foresight studies on telecommunications and attempts to standardize future technologies share some common features. Future foresight studies would benefit from collaboration with experts involved in telecommunications standardization. After all, in some standardization projects (FPLMTS, UMTS) the time horizon is long enough to be of relevance from the point of foresight studies.

Foresight studies would also benefit from following the example of standardization efforts in adopting an international perspective. National differences are of less and less importance as we approach the era of information society, where endowments of natural resources and differences in climate are of lesser importance than the characteristics of the national innovation systems.

Foresight study methodologies have to be further developed. Ways have to be found to extract more detailed visions of future developments. In addition, ways to grade the experts' inputs have to be further refined. The true visionaries are always minorities among their peers.

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The economic analysis of innovation based economies needs different concepts and tools than the analysis of factor-driven economies. The focus of this book is on these new concepts and tools. There are few ready answers to be given. The new conceptual framework of e.g. evolutionary economics is still evolving. The concept of the national innovation system, which is aimed to replace the traditional concept of "national competitiveness", is still seeking its exact content.

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