MAPP working paper no 10
October 1993
ISSN 0907 2101

Technological Opportunities and Paths of Development

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Executive Summary

1) The technological development of firms in an industry is influenced by the opportunities for improving product and process, their ability to identify such opportunities and their ability to appropriate the benefit of the development effort.

2) Firms' historically developed technological knowledge, their production, development and other routines as well prior investments in products and production equipment play an important role with regard to the technological opportunities that firms' identify and select for development.

3) Because history matters and because firms are bounded rational they tend to choose opportunities for incremental improvements in their products and production techniques rather than developing radical new products and techniques.

4) Persistent differences between firms in an industry with regard to their products and process technologies are an outcome of the interplay between opportunities for improvement and differences in firms technological competencies and appropriation ability.

5) However, differences between firms in their technological development tend to narrow down to different ways of improving what has become a dominant product or production design in the industry.

6) It is argued that such paths of incremental improvement at the industry level may be an outcome of a) the dynamics that produce the technological opportunities; b) the institutions that govern decisions and expectations and c) the criteria by which the market chooses between different firms technological development efforts.

7) The dynamic that produces opportunities for technological development will in part depend on characteristics of the product (e.g., its complexity), the interdependence between the product and production techniques, the diffusion of the product and in part on the accumulation of technological knowledge that makes possible the identification of new technological problems and solutions. These dynamics produce a limited and coherent stream of opportunities once a dominant design has emerged in an industry.

8) The dominant design, reducing uncertainty in both the market and technology dimension, represented a more attractive line of development than developing alternative solutions. The dominant designs' position in an industry may also be strengthened by institutions such as technological communities and techno-economic paradigms.

9) Finally, the market selection between the outcome of different firms development effort may also help shape a path at the industry level. This may be because the criteria by which the market selects between the different product may to some extent be anticipated by the developing firms or because the criteria by which the market select between different solution may be such that only those solutions that represent incremental improvement in a dominant design will be chosen.

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1. Introduction

This paper presents the theoretical frame of the project: "Strategic planning and the innovative ability in the Danish food sector". The project is part of the *MAPP research programme*, which again is part of the larger *FØTEK programme*.

The primary purpose of the above project is to contribute to a theoretical understanding of technological *development* and *change* in an industry.

The underlying assumption is that the technological development in an industry is strongly influenced by *opportunities* for technological development, the individual firms' *innovative capabilities*, and their potential for *appropriating* the benefit of the new technologies.

In the process of *technological development*, the individual firms develop and introduce new or better production techniques and new products. Which of the new technologies gain economic weight is an outcome of the process of *technological change*.

This latter process is driven by a selection of different products embodying different performance characteristics and prices and by implication a selection of different technologies embodied in firms.

Technological variety is the outcome of technological development efforts in firms and research institutions. The development process in an industry therefore strongly influences the technological change process, as it is on this variety that the forces of natural selection work. However, technological development not only produces variety, it also alters the terms of technological competition as new product features are introduced, and as the level of productivity in industries changes.

The paper is in two parts. *Part on*e gives an overview of the theoretical frame for the whole project. This presentation includes a brief introduction to evolutionary theory as an overall theoretical frame. Within this overall frame three groups of theories are considered, viz.: technological paths at the industry level, theories on technological competencies and learning, and theories on appropriability, all central to an understanding of the more specific question concerning the relation between technological development and change.

Part two provides a more thorough presentation of the theories of technological paths. In this part focus is on how a number of *technology internal factors* set a limit to technological variation, and also on how these factors change over time, and shape the technological change process in, e.g., a food processing industry.

The various theories on *technological paths* or trajectories point to some of the important technology internal factors that give rise to opportunities for technological development in an industry. The theories also indicate some of the factors that reduce the technological variety between firms, and shape the technological development into a coherent path.

An example of this approach is Dosi (1988), who argues that the accumulated knowledge and the artefact belonging to a so-called "technological paradigm" together define the technological opportunities for further innovation in products and processes. Other contributions to an understanding of technological paths are Laudan's (1984) and Constant's (1984) discussion of how the tradition and knowledge in the technological communities direct the search for technological opportunities and Abernathy's (1978) and Sahal's (1984) description of how a dominant design emerges in an industry and helps structure the technological development.

Common to all these somewhat different definitions and explanations of technological paths in existence are, however, the following three sub-factors which together explain the coherent path of technological development in industries. These factors are:

1) The dynamics that produce technological opportunities are of such a nature that *the opportunities* for technological change are limited by a technological guidepost and emerge in a coherent fashion from the knowledge and techniques already in use.

2) The path of incremental improvements in a technological guidepost is sustained by firms and *institutions* in the economic system that govern decisions and expectations.

3) Finally the economic activities are of such a nature that the *selection environment* is rather homogenous and the selection between the available variety of implemented technological solutions reduces the number of surviving technologies to those that represent only incremental improvements in prior technologies.

PART ONE

2. An evolutionary perspective on technological development and change

The overall theoretical frame to be considered is represented by evolutionary theories of technological change.

In the biological science the core of what has come to be known as the "neo-Darwinian theory" (Mayr, 1982) is a standard form of natural selection - the selection of biological characteristics through the differential reproduction of individual organisms.

Neo-Darwinism and the extension of it to the "modern synthesis" does not provide a unifying model for the evolution of the biological systems, rather: *"The modern synthesis is a set of ideas which is sufficiently broad and variable to accommodate a multitude of truths and sins"* (Mani, 1989, p. 30). However, Hannan and Freeman (1989) have outlined some of the basic ideas in the "neo-Darwinian" theory as:

Firstly, the theory claims that the underlying evolutionary processes are timeless. It establishes that all existing organisms are descendants of one or a few simple ancestral forms.

Secondly, the mechanism for evolutionary change is natural selection operating on the variations in the population. The mechanism that creates variation in a population is either mutation of genes or sexual recombination.

The third element in neo-Darwinian theory is that organic evolution is broader than natural selection, because evolutionary change in biotic populations also comes about through random genetic events such as genetic drift and founder effects.

A more general definition of evolutionary change can be found in Lewontin (1974) and Van Parijs (1981), who use the term evolutionary to describe the theories that deal with understanding the succession of changes of the state of a universe in time, where these changes can be characterised either by their overall direction or by an underlying mechanism or law of transformation.

In the world of the social sciences, economists such as Nelson and Winter (1982) or Metcalfe and Gibbons (1989) have used the analogy to Darwin's natural selection[1] to explain the laws of transformation of a system over time[2].

In their models, the evolutionary explanation of economic change is perceived as driven by two distinct but related forces, where

[1] Nelson and Winter (1982) apply the evolutionary perspective to the question of the effects of technological change on macro economic growth. Metcalfe and Gibbons (1989) have applied the perspective to the question of distribution of different technologies in an industry.

[2] The use of an evolutionary perspective in economics requires that it is determined what are the analogies to the mechanism of variation, selection and retention/heredity.

"..the first generates the economic variety and the second selects between those varieties to change their relative economic importance over time" (Saviotti & Metcalfe, 1991, p. 11).

In other words, a mechanism that produces "mutations" (the economic analogy would be innovations) is involved, as is a selection mechanism (in economics, the analogy is competitive market selection).

According to Van Parijs (1981), there are only two basic types of evolutionary mechanism, viz. the natural selection and the reinforcement mechanism. Natural selection changes the distribution of some features in a population by selecting on the units carrying these features. The reinforcement mechanism, on the other hand, works within the units resulting in a selection of the features which are functional in the sense that they maximize the unit's chance of satisfaction in accordance with its preferences.

What is being explained by means of natural selection in evolutionary economic theories is the presence of a persistent feature, such as a type of artefact or knowledge in a typical firm in, e.g., an industry.

The process of *natural selection* is one of "equilibration through consequences", as the philosopher, Philippe Van Parijs (1981), puts it. By this he means that it works on the *available* variety, and reduces it to those variants which are *better adapted* to the selection environment.

Another requirement of a natural selection explanation is

"..that the features whose presence is being explained are selected through the differential survival and/or reproduction of the entities which the features characterize. By "differential ", I mean that the probability of survival and/or reproduction of the entities depends causally on whether or not the features which are being explained are present" (Van Parijs, 1981, p. 32).

As pointed out by Van Parijs, it is essential that variety created by firms' differentiated technological development has *selective significance* for natural selection to function as the law of transformation.

If technology has no influence on firms' *competitive positions*, then technological change in an industry cannot be explained in terms of natural selection. But as Metcalfe and Boden (1990) note:

"Although technology is not the only source of competitive advantage for our firms, it is a vital one in the context in which a firm may change drastically its core activities" (p. 3).

When technology *does* influence the competitive positions of the individual firms, then the technological variety drives the process of economic change through the effect of various technologies on the firms' competitive advantage vis-á-vis the selection forces. *Technological variety* is therefore a central issue in relation to any evolutionary explanation of economic change.

Now, it is important to distinguish between 1) the process of *technological development*, which is a *transformational change* process that creates variation in the selection units, and 2) the process of *technological change*, which is the outcome of the *variational change* process that alters the distribution of technologies. Natural selection can *only* explain the process of technological changes, and only in absence of vast and fast technological diffusion[3].

The process of *technological development* is extremely important to the process of *technological change*, since technological opportunities and thus the potential variation between firms depend on prior technological developments.

As suggested by Dosi and Orsenigo (1988) technological development may be evolutionary in the sense that it consists of incremental cumulative irreversible changes. This, however, does not mean that the process can be explained solely in terms of evolutionary mechanisms such as natural selection and reinforcement.

In fact, Saviotti and Metcalfe (1991) have argued that the fundamental contrast between the biological and the economic world of evolution is that in the latter the generation of variety is purposeful (see already Penrose, 1952):

"Firms deliberately seek to differentiate themselves from rivals through a multitude of types of product and process innovations, and while this process undoubtedly contains random elements it is also shaped by the environment in which firms operate" (p. 11).

For the process of natural selection to work, it is important that the variety generated in the process of technological development is *blind* in the sense that it is not connected with the criterion of selection. In the biological world, the process that creates variation is totally independent of the process of selection among the variants, whereas in the economic sphere the selection criteria clearly also influences the generation of variety.

As Penrose (1952) noted in a critique of evolutionary reasoning in economics (represented by Alchian, 1950), firms can to some extent anticipate their future selection environments. But the *behavioural assumptions* of bounded rationality and organisational inertia that are so central to evolutionary theories on technological change (see Nelson & Winter, 1982, chapters 4 and 5) imply that in most cases intentions do not perfectly adapt the firm to the selection environment.

The intentionally planned technological development in firms and research institutions produce variation at the industry level which - depending on the uncertainty - may be *random* or *biased* with respect to the selection criteria. In either case, it is the quality of the selection environment that ultimately determines which of the technological variants that will survive

[3] Limited diffusion of technologies and rigid adaptation on the part of the firms focus interest on the variational change process. Nelson and Winter explain it in this way: "This appraisal of organizational functioning as relatively rigid obviously enhances interest in the question of how much aggregated change can be brought about by selection forces alone" (Nelson & Winter 1982, p. 10).

and gain *economic weight*. The amount of variation between technologies that survive depend on the strength of the selection forces and on the segmentation of the selection environment.

In most models, it is assumed that *price competition* is a very important element in the *selection environment,* so that the firm with more efficient technologies is favoured relative to ones with less efficient technologies. In some of the food processing industries, this may be a very close approximation to the selection forces at work. But it is also possible to envisage a number of other important criteria, such as flexibility in production or adaptedness to governmental regulations.

Central to a process of evolutionary change is the co-evolution of the unit of selection - the firm - and the selective environment. As firms continually change their technologies, the *terms of competition* in an industry change. The important thing to note is that in this perspective firms' competitive advantages from different kinds of technology are continously changing with changes in the selection environment (Metcalfe & Gibbons, 1989).

The importance of variation in evolutionary theory has inspired my interest in understanding the mechanism that generates technological opportunities as well as the mechanism that limits the development at the level of firms and industries.

The following section provides a more detailed description of various evolutionary approaches that will be applied to the question of technological variation between firms within this overall frame of evolutionary theory.

Part two of this paper discusses more explicitly the factors that create a bias in the technological variation relative to the ex-post market selection.

3. Some specific theoretical contributions within the overall evolutionary frame

Within the above presented overall frame of evolutionary theory, focus in this section is on technological variation between firms in an industry. The theoretical contribution to this more specific question emerges from the following three groups of theories:

1) Theories on technological development at the industry level,
2) Theories on firms' capabilities
3) Theories on appropriability.

Below a short presentation of the contributions from each of the above-mentioned theories is given.

Theories on technological development at the industry level

This group of theories primarily includes theories of technological paths. It is exclusively these industry-level oriented theories of technological development that will be more extensively dealt with in part two of this paper. However, a few points about these theories will also be presented here.

A prominent example of this approach is Dosi (1988), who argues that the accumulated knowledge and the artefact that belong to a so-called "technological paradigm" together define the technological opportunities for further innovation in products and processes. Further examples are Constant (1984) and Laudan (1984) - both using the concept of technological communities - who give a more detailed description of the role of knowledge in shaping technological paths. Rosenberg's (1982) discussion of the links between science and technology also serves as an inspiration to the identification of the knowledge characteristics of the opportunity set. Sahal's (1984) study of technological development from an artefact perspective indicates how the systemic character of products and processes places a limit on the generation of opportunities. And Abernathy (1978), taking the productive unit as the unit of analysis, shows how the interplay between product and process changes over time and alters the kind and the amount of opportunities that can be discovered and exploited.

Theories about technological learning and competencies at firm level

My understanding of the concept of *technological competencies* is based on literature on firms' technological development and learning, especially those theories that fall within the evolutionary perspective (Nelson & Winter, 1982; Metcalfe & Boden, 1990; Metcalfe & Gibbons, 1989; Dosi, Winter & Teece, 1990). Further inspiration is obtained from the so-called resource-based perspective (Wernerfelt, 1984 ; Dierickx & Cool, 1989), and theories on organisational learning (Cohen & Levinthal, 1990; Jelinek, 1979).

Evolutionary theories on firms' competencies serve as the overall organising frame for the discussion, while the resource-based perspective and theories of organisational learning are utilised for addressing more *specific* problems.

A review of this literature has made me focus on the following aspects of competencies:

a) the absorptive capacity of firms;
b) firms' technologies in the form of artefacts;
c) firms' technologies in the form of skills, routines etc.

Within the evolutionary theory of Nelson and Winter (1982), structures, habits and routines play a similar evolutionary role to that of the *gene* in the natural world. *Routines* pass on *skills* and *information* over time, i.e. they function as "hereditary systems". What is "inherited" within the firm is the ability to perform production transformations as embodied in organisational rules and routines. Nelson and Winter make it clear that routines do not act as genes in the neo-Darwinian sense but in the Lamarckian sense, precisely because of the general condition of the social-scientific domain, that inheritance of acquired characteristics is possible.

Firms' competencies set the limit to the opportunities they will discover and take advantage of. Because competencies are historically developed and difficult to change, firms' technological development is path-dependent in the sense that the opportunities they take advantage of are closely related to the competence endowment of the firm.

The evolutionary perspective also draws attention to the interplay between technology in terms of artefact and the development of skills necessary for the operation of the technology and the development of procedures co-ordinating the various individual tasks. As Nelson and Winter (1982) point out: *"..skills, organisation, and "technology" are intimately intertwined in a functioning routine, and it is difficult to say exactly where one aspect ends and another begins"* (p. 104).

The difficulties and the cost of implementing new technological solutions that require major changes in such a complex system may very well deter some of the firms from taking advantage of such (most likely externally generated) opportunities.

In *the resource-based perspective* - which is in some respects closely related to evolutionary theories - firms' capabilities are analysed from the perspective of their ability to earn above-normal profit, or rather, rent. Firms are assumed to possess heterogeneous, idiosyncratic and historically generated resources that cannot be transferred among firms, due to their special characteristics. It is also these characteristics that explain why such resources may possess a rent-earning potential. Among the most important resources are the firms' idiosyncratic technological competencies. Since rent-generating resources are not freely available, firms' resource endowments set a limit to the opportunities they can exploit. The normative implications drawn from this perspective is that within these limits firms should choose to develop in directions where their resource endowment in terms of, e.g., accumulated experience is superior to competitors.

Theories of organisational learning permit a more fine-grained identification of the character of firms' technological competencies and how they *develop.* An important representative is Cohen and Levinthal's (1990) theory about firms' *absorptive capacity*, defined to be the *"..the ability of firms to recognise the value of new, external information, assimilate it, and apply it to commercial ends"* (Cohen & Levinthal, 1990, p. 35). This ability depends on the accumulation of prior related knowledge. As such the absorptive capacity functions as a cognitive constraint that limits the kind and the amount of opportunities firms can take advantage of.

The importance of prior related knowledge has two implications for the amount and kind of opportunities firms can take advantage of. First, the accumulation of absorptive capacity in one period will permit more efficient accumulation in the next; second, it affects firms' expectation-formation - permitting it to predict more accurately the nature and commercial potential of technological advances. Lack of absorptive capacity, on the other hand, creates what Cohen and Levinthal term a "lockout", in which the firm does not become aware of technological "signals" in its environment.

Cohen and Levinthal furthermore distinguish between *external* and *internal* absorptive capacity. *Internal* absorptive capacity is for the most part rooted in experience (what Rosenberg (1982) calls "learning by doing" and "learning by using"), and produces incremental technical change (what Clark and Abernathy (1985) call "niche creating" and "regular" innovations). The *external* absorptive capacity is largely a function of the firm's R&D-efforts, but it also depends on such factors as the firms' interface with the environment, how externally generated knowledge is acquired and communicated inside the firm, the quality and diversity of employee knowledge and background (e. g., their belonging to different technological communities).

Cohen and Levinthal's thesis is that absorptive capacity influences aspiration levels (Cyert & March, 1963), and consequently firms' investment behaviour. When aspirations are founded on internal absorptive capacity, functional failures in technologies are likely to be the factor that triggers investment. And when aspirations are founded on external absorptive capacity, recognition of externally generated technological opportunities will also trigger investments.

To summarise: Focusing on competencies derives importance from the fact that within the limits set by the opportunities for technological development, firms' actual technological development depends on their technological competencies.

Clark and Abernathy's (1985) *transilience map* is useful for illustrating this point. They describe the relation between opportunities and firms' competencies in what they call the transilience map. This "map" is a two-dimensional taxonomy of technological innovation that distinguishes between four types of innovations on the basis of their capacity to influence firms' existing technological and marketing competencies:

> *Architectural*: radical technology applied to new markets;
> *Niche creation*: refinements in technology applied to new customer groups and new applications;
> *Regular:* refinements in technology applied to existing markets and customers;
> *Revolutionary:* disruptive change in technology applied to existing markets and customers.

My thesis is that a "given" technological opportunity may be interpreted as regular in one firm, and as revolutionary in *another* - depending on the individual firms' competencies.

On theoretical grounds, it is expected that different levels of absorptive capacity in firms create variation in the kind and amount of opportunities that they take advantage of. This is because firms recognise and evaluate opportunities differently depending on their absorptive capacity. Differences in the extent to which firms have developed their internal or external absorptive capacity may explain, why some firms primarily take advantage of opportunities generated within the firm, while others to a larger extent also take advantage of opportunities generated outside the firm.

The competencies possessed by firms are related to their vertical and horizontal specialisation in the chain of production. The opportunities that firms can take advantage of will therefore also depend on the functions carried out by them.

It is also expected that the *systemic* character of firms' technologies, skills and routines direct their search for opportunities towards "more of the same" rather than into areas that require a "major restructuring" of the organisation. The cost of implementing major changes may also function as a selection criteria where incremental improvements in existing technologies are preferred over more radical solutions.

There is yet another aspect of this set of problems that has to be taken into account viz. the extent to which decision makers select technological solutions on the basis of avoiding future rigidity problems.

Theories about appropriability

The most important inspiration is Teece's (1987; 1988; 1992) discussions of core competencies and regimes of appropriability.

Teece described some of the important mechanisms (such as patents, secrets, vertical integration etc.) that firms develop and utilise for the purpose of appropriating benefit from innovations. Teece (1987) argues that firms' ability to appropriate the benefits of innovations differ depending on the *regime of appropriability.*

The two most important dimensions are:

1) the efficacy of *legal mechanisms* of protection such as patents, copyrights, and trade secrets, and
2) *the nature of the technology*. The nature of the technology refers to the ease with which competitors can imitate the core technology of a firm.

When a technological opportunity is identified as being in a weak regime of appropriability (the innovations are easily imitated and not well protected by legal means), the firm can only earn rent from exploring the opportunity, if it possesses other means of protecting the innovation from diffusion. Such means may be specialised or co-specialised assets. If firms acquire such a specialized asset, they often end up representing an irreversible investment. It is therefore likely that the utilisation of the investment will be an important criteria on which the firm bases its selection among the opportunities for innovations (Dosi, Teece & Winter, 1990).

4. Some overall theses on technological variation

Having identified the three major theoretical inputs to this project, I shall briefly indicate how they are related.

The central organising *theoretical* theme applied to the issue of technological variety is that the individual firms' technological development is created at the intersection of:

1) the technological *opportunity set* in the industry.
2) firms' historically developed *competencies*,
3) their *appropriation* possibilities.

The three above-mentioned groups of theories address the concepts of *opportunity, competencies,* and *appropriability,* respectively.

The *overall thesis* is that within the limits set by the opportunity set, the differences in firms' competencies and perceived appropriation potential create variation in firms' technological development in two ways:

Firstly, their competencies determine which opportunities they discover.

Secondly, the competencies and the appropriation potential function as internal criteria that determine which of the discovered opportunities the firm will take advantage of.

The forces of natural selection work on this available variation between the firms and reduces it. As the process of technological change proceeds both the opportunity set and firms' competencies change. In the succeeding stage, new variety is introduced in the form of innovation, which in turn is a function of different sets of opportunities and firm competencies.

I am now in a position to present in more detail the theoretical aims of the research project, which is to obtain an understanding of how the *interplay* between the opportunity set, individual firms' competencies and their appropriation potentials *shape the technological variety and development* within an industry.

Besides the theoretical goal described above, the project has an empirical component. This empirical component aims at providing evidence of the technological opportunity set, and of how technological variety is created as a consequence of the differences in firms' capabilities. The identification of such problems of a technical nature in the relevant firms takes place in collaboration with The Biotechnological Institute and will be reported separately in 4 research papers.

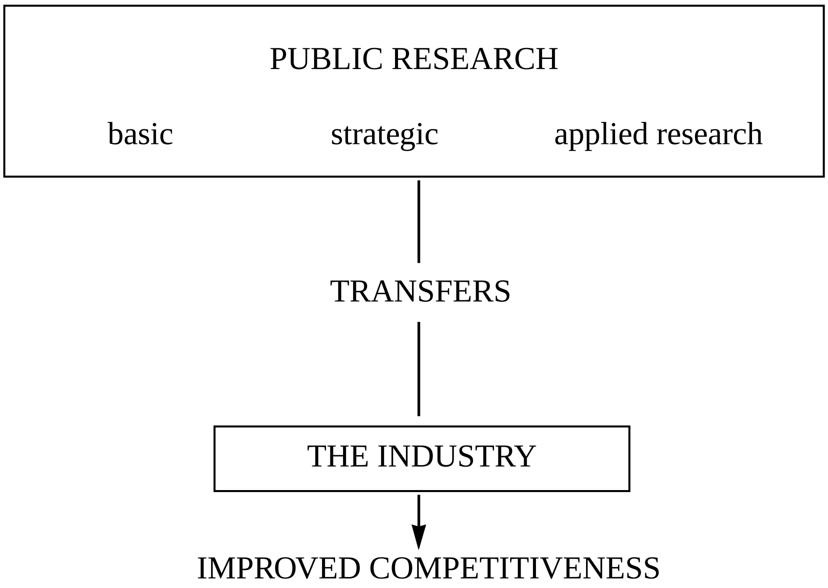
5. The FØTEK programme and technological development

The theoretical as well as the empirical components of the project are closely related to the overall purpose of the FØTEK programme.

FØTEK was created in order to enhance the innovative ability of firms in the food-sector by (partly) funding technological development projects of firms and public research institutions. The ultimate aim is a technology induced improvement in the firms' competitive position and thus their profitability.

The FØTEK programme is based on a linear model of technological development which is illustrated in figure 1. This model gives a rough sketch of how this effect of the FØTEK programme is perceived to come about:

Figure 1. The linear model of technological development



The three stages in the above model will be briefly commented on below:

1) There are a number of technological problems and solutions of which firms are unable to take advantage due to lack of finances and technological know-how. An increased publicly supported technological development will help solve these problems and result in a number of inventions.

2) These inventions are transferred more or less unproblematically to firms in relevant industries and

3) the inventions are transformed into innovations which ultimately benefit the firms' competitive position.

The understanding of technological development in the food processing industry emerging from this project is somewhat different. Some examples will illustrate this point:

Example 1: The strategic importance of technological development depends on the competition between firms.

In the fish filleting industry, where technological variation between firms narrowed down to minor differences in the organisation of the production process, even minor improvements seemed to have great impact on the competitive position of individual firms (high selective significance).

In fact, in industries, such as the fish filleting industry, where opportunities for enhancing productivity and products were very limited, the competitive pressure tended to be greater than in industries with more technological opportunities.

Example 2: Firms compete on technology.

On the one hand, one would expect that the greater the strategic importance of technological development the higher the firms' incentives for technological development. Firms in industries such as the fish filleting industry, would be expected to show an interest in the FØTEK programme.

One the other hand, the homogeneity in the filleting firms' technological configurations implies that most likely new solutions could be a benefit to all firms, and that these solutions in principle could diffuse very fast. At the same time the homogeneity between firms results in strong price competition. Each firm therefore has a great incentive to keep any technological advantage to themselves. And in fact firms in the industry sought to prevent diffusion by a very high degree of secrecy. The possibility of breaking this secrecy seemed to deter firms from participating in the FØTEK programme. But also in industries, where technological variety between firms was greater, firms were reluctant with regard to participating in the FØTEK programme.

This was for instance the case in the bread industry where solving the problem of reducing artificial additives without loosing shelf time was considered of strategic importance. However, firms were not willing to share their knowledge with other agents.

The ability of any individual firm to solve the problems was considered of such competitive importance that none of the firms with the problem-solving potential were willing to collaborate with other firms or public research institutions.

Example 3: Firms differ in their technological competencies.

Some firms are barely able to identify technological problems and they certainly do not have the resources to participate in a development project, let alone to implement technological solutions produced by FØTEK researchers. Other firms - especially the larger ones - are definitely capable of both identifying technological problems and participating in solving them.

To some extent such differences seem to be industry specific. At least the preliminary study indicated such differences between the bread industry and its enzyme supplier industry.

In the bread industry, the selection criteria employed by the bread producing firms led them to develop in rather narrow paths with only limited variation between firms at the industry level.

The development consisted of minor improvements in production techniques reflecting the limited technological competencies. In general, the bread producing firms would identify opportunities based on their accumulated experience and craft traditions. It was evident that - unless the technological solutions could be bought at a reasonable price - the bread firms would rather take advantage of internally discovering opportunities of the learning-by-doing kind.

Development in bio-technology may open up a whole new opportunity set, based on scientific knowledge. The initiation of such changes in the opportunity set was observed, but changes were primarily induced by the research institutions or the enzyme supplier firms rather than by the bread producing firms themselves.

The enzyme supplier industry has, as opposed the bread producing firms, internal R&D as well as a long tradition for co-operative relation between firms and research. This meant that to a larger extent they were aware of these externally discovered opportunities.

The FØTEK programme could be a means of strengthening the bread producing firms' position relative to their supplier industry. But this would require a long term investment in upgrading the firms' technological competencies within the area of new bio-technology.

The preliminary result of the study conducted in the bread and fish processing industries indicate that the FØTEK programme may have more or less unexpected results on technological development and change process in an industry.

It is not easy to give a qualified guess as to how exactly FØTEK influences technological competition. But on the basis of the above observations, as well as the theoretical studies, I would expect it to depend on:

1) how much the new technological solutions would increase efficiency or product quality;
2) the competition in the industry;
3) the rate of diffusion of technological solutions; and
4) differences in firms technological competencies.

It seems, that in order to fully comprehend the effect on the technological development and change processes of a programme like FØTEK, much more theoretical work is needed on the relation between the technological opportunities, technological variation and competition in the industry.

PART TWO

6. An overview of the second part of the working paper

In this part of the paper theories on technological paths are introduced as a way of gaining insight into the factors effecting the technological development in an industry.

This part of the paper contains the following major elements:

1) A definition of the concept of technological opportunities,
2) A definition of technological paths,
3) A discussion on technological paths and limits to variation.

In *section 6* the *concept of technological opportunities* is discussed. Technological opportunities play a central role in shaping both technological development and technological change process since they set the limits for both the technological development within a firm, and for the amount of technological variety that can be found in an industry at a given time.

Section 7 outlines two *complementary theoretical and empirical approaches* to the study of technological path viz. the artefact and the knowledge perspective.

In *section 8* it is discussed how the theories on paths may enhance our understanding of technological development and variation in an industry. This is inspired by Orsenigo and Dosi (1988), who view market based patterns of change as the outcome of *three self-organising factors*, viz.:

a) the dynamics of technological development which influence the opportunity set and its evolution,
b) the institutions that govern the decisions and expectations, and
c) the natural selection that work on the available variety.

Each of these self-organising factors is discussed separately in the following three sections.

In *section 8.1* the dynamics of technological development as described in theories of technological paths are examined and particularly the explanations regarding the emergence of technological opportunities in an industries.

A close inspection of the arguments on technological paths reveal that the dynamics of technological development will enforce a coherent development in the opportunity set, which is specific to a given technology. But it will not produce a path of development at the industry level unless a dominant design or guidepost has emerged.

In *section 8.2* it is argued that such a guidepost may represent an *"evolutionary attractor"* (Van Parijs, 1981), because it is less uncertain and thus less costly for firms to develop their product along the lines of a guidepost. Its position as such an attractor may then be strengthened by *institutions* governing the technological development. Such institutions may be the traditions of technological communities (Laudan, 1984; Constant, 1984), as well as a techno-economic paradigm controlling the interface between groups of users and producers (Andersen, 1991).

The self-organising factors discussed in section 8.1 and 8.2 work ex-ante relative to market selection. They help produce a coherent development and they reduce the amount of technological variation on which the selection forces work.

It is important to remember, however, that natural selection also plays an important role in shaping paths, because only the technologies selected by the market shape future opportunities for development. The criteria by which technologies are selected by the market may themselves also be important elements in the forces directing the technological development ex-ante the market selection.

The terms of technological competition and, by implication, the selection environment are continuously changing, since the criteria, on which products are selected, depend on unpredictable ways on the firms' cumulative technological developments. In this perspective, it is of great interest to understand, how the selection environment and the technological development may co-evolve.

Section 9 briefly discusses the interplay between the selection environment and factors that shape the technological development.

7. Technological opportunities

Before moving on to a more thorough discussion on technological paths and the evolution of the opportunity set, the concept of technological opportunities, and how it is related to technological variety in an industry, will briefly be discussed.

A technological *opportunity* is defined as either:

1) a problem that is identified and perceived of as a technical problem, or
2) technical solutions - or approaches to solutions - novel to existing technical problems in the industry. The solutions can be embodied or dis-embodied technology (new machines or techniques).

It may not be practical to distinguish too sharply between problems and solutions, since very often problems are not defined as technological problems, unless there is some understanding of how to solve the problem by technological means (Wojicek, 1984).

The opportunity set is made up of opportunities defined in firms, in research institutions, in suppliers and in collaborative arrangements (such as FØTEK). As Freeman (1982) points out, the role of the individual firm, in shaping the opportunity set, is generally limited. The opportunities, firms can take advantage of, are a function of historical developments in the factors that shape the opportunity set. Among these factors are scientific progress and technological development in up- and downstream industries.

The exploration of technological opportunities may result in different kinds of innovation such as:

"...new products, a new process of production; the substitution of a cheaper material, newly developed for a given task, in an essentially unaltered product; the reorganisation of production, internal functions, or distribution arrangements leading to increased efficiency; better support for a given product or lower costs; or an improvement in instruments or methods of doing innovation" (Kline & Rosenberg, 1986, p. 279).

Firms may have a number of different sources of new technology. Inside firms there are the technicians employed in R&D departments and production, and outside firms, there are suppliers, users, and research institutions. The source of new technology as primarily internally or externally acquired, may vary between firms and industries (Dosi, 1988; Pavitt 1984). In fact, in Pavitt's study (1984) differences between firms with regard to the source of new technology were an important variable characterising different sectoral patterns of technological change.

In order to understand the limits to technological development within an industry, it is therefore necessary that the analysis include the whole chain of production as well as the publicly financed R&D institution in contact with the industry.

Technological opportunities and variation in an industry

Technological variation between the end-producing firms may come about because the firms differ in their own innovations or in the technological solutions they acquire from their suppliers.

If the supplier industries have the majority of opportunities then the technological variation between firms in the end-producing industries depend more on their supplier relations than on their individual development activities.

The relation between *technological opportunities* and *technological variety* is schematically illustrated in the figure below.

In general it can be said that if the opportunity set is of such a nature that a large number of problems may be identified, and to each of these problems a number of solutions can be found, the potential for variation is large.

But when all solutions and problems are found within the *end-producer* industry, the realised variation is likely to be larger than if the opportunities are in *the supplier industry*, since the diffusion of the better solutions would be easier in the latter case[4].

A better understanding of the limits and the characteristics of the opportunity set will be based on theories about technological paths in industries and technologies which I shall return to in the following sections.

Figure 2. Technological variety and technological opportunities

		Identified problems	
		many	few
Developed solutions	many	large variation	variation primarily with regard to selected solutions
	few	variation primarily with regard to ranking of priority of problems	small variation

8. Theories on technological paths

Most of the theories applied fall within the tradition that places the study of the internal dynamics of incremental improvements in technologies at center-stage (Abernathy & Clark, 1985; Sahal, 1981; Laudan, 1984; Constant II, 1984; Clark, 1985; Rosenberg, 1982).

As Laudan (1984) puts it:

"External factors like economic and social also play a role in the selection of technological problems and solutions. Nonetheless the problems have to be perceived as soluble to technological means, and the technologies themselves have to be created. Without such internal technological capabilities all the economic and social pressures in the world would be of no avail" (p.4).

The *technology internal dynamics* are, e.g., the physical characteristics of products and production processes; the experience and technological knowledge accumulated within different research and development traditions. Dosi has captured most of the technology internal factors in the concept of *technological paradigm*:

" A "technological paradigm" defines contextually the needs that are meant to be fulfilled, the scientific principles utilised for the task, the material technology to be used. In other words, a

[4] It is important to emphasize that the opportunity set limits the technological variation and development, but that the technological change process does not depend only on the amount of variation. The technological change process depends also on the selective advantage vis a vis the competing problems and solutions.

technological paradigm can be defined as a "Pattern" for solutions of selected techno-economic problems based on highly elected principles derived from the natural sciences. A paradigm is both a set of exemplars - basic artefacts which are to be developed and improved.........and a set of heuristics-"where do we go from here?" "Where should we search?, "On what sort of knowledge should we draw?,""(Dosi, 1984, p. 224).

The *technology external* factors include such factors as socio-economic changes, scarcities of critical input, changes in relative prices, changes in customer demand.

These technology external factors *induce the technological development* but they do not determine the actual outcome of the change process. As Dosi explains:

"With positive technological opportunities, the economic agents tend to react to (or anticipate) changes in relative prices and demand conditions by searching for new techniques and new products within the boundaries defined by the nature of each technological paradigm" (Dosi, 1984, p.17).

In a similar manner Rosenberg (1985) has argued that the ultimate incentives for technological change are economic in nature but:

" ..economic incentives to reduce cost always exist in business operations, and precisely because such incentives are so diffuse and general they do not explain very much in terms of the particular sequence and timing of innovative activity" (p.110).

In other words, a change in relative prices on labour and capital in favour of the latter will induce a search for solutions that can replace expensive labour with capital. It may also alter the economic feasibility of some technological solutions prior to others and thus enhance the diffusion of these technologies. But the external factors do not influence what kind of technological solutions technicians come up with.

An enquiry into factors influencing technological variety in an industry should ideally take into account how both technology external and internal factors exert influence, as may be illustrated by the following example from the food processing industries.

In some of these industries changes in consumer demand and desires have resulted in a demand for products that are more natural and healthy. This change in demand has in turn initiated a search for different means of replacing the artificially produced preservation products. In this specific case the external change meant a widening of the opportunity set since a larger number of technological solutions were now considered.

The trajectory is the actual technological progress, the technological problems and solutions chosen among the possible set of opportunities defined by a paradigm (Dosi 1986,1988).

Unfortunately lack of space and time requires this problem to be left aside. Only theories on technological paths produced by technology internal factors will be on the agenda in this paper.

Definitions of technological paths

Rosenberg (1985) has described technological development as a cumulative and self-generating process. And from the research of, e.g., Dosi (1988), Rosenberg (1976, 1982), and Sahal (1984) also the notion of "technological trajectories" has emerged which describe an ordered pattern of technological development that is cumulative and self-generating, without repeated reference to the external economic environment of the firm.

In the literature on paths (or trajectories) of technological development, two different but not incompatible ways of studying paths are identified, viz. from a *knowledge perspective* (Laudan, 1984; Constant, 1984) and from an *artefact perspective* (Sahal, 1981; Abernathy, 1978).

The *artefact perspective* views the paths as a set of incremental changes in products and processes. Paths of development are opposed to *radical changes*, where either new design approaches or totally new product and processes are introduced.

Among the several difficulties - that emerge when wanting to document a path of technological development in an industry - are the problems of how to discriminate between incremental changes and radical change in a product or process.

In a product or process that consists of many *components*, some of them may change drastically, whereas the overall design does not change.

Sahal has tried to develop a measure of technological development that *"makes it possible to take into account both major and minor innovations and to assign appropriate weights to their importance according to a certain common denominator"* (Sahal, 1981, p. 28).

For this purpose he has introduced *a system concept of technology* that focuses attention on changes in the functional characteristics of technology. According to Sahal the path of technological development can then be described by establishing a measure for the *functional characteristics* of technology. In, e.g., a tractor, the development can be described as changes in horsepower-hour per gallon of fuel or the horse-power-to-weight ratio. Major improvement of the function could indicate a break away from the path as when, e.g., a new and much better design approach is introduced. Such a perspective can, of course, best be used where it is possible to measure the improvements objectively. Improvement in food products are often difficult to measure in this way because no "objective" measure for improved taste or texture exists.

Sahal's measure of technological paths does not solve the problem quite satisfactorily, since it does not take into account that major improvements in functional performance may come about by minor changes in technology and vice versa.

Two *complementary approaches* to describing the path of development - which deal more explicitly with this problem- are developed by Clark (1984) and Metcalfe and Saviotti (1985)

(see appendix).
The knowledge perspective - represented by, e.g., Constant II and Laudan (1984), is a somewhat different approach to technological paths. In their opinion technological development is best understood by focusing on:

"..the skilled and purposeful action of a handful of practitioners, applying their accumulated knowledge to solve technological problems,.." (Laudan, 1984, p. 5).

Whereas the artefact perspective views technological paths as incremental changes in a basic design approach, the knowledge perspective views it as a process of knowledge accumulation.

The knowledge accumulation takes place:

"..as these practitioners develop new technologies, the pool of knowledge that they share shifts. Thus an important avenue to understanding technological change is to analyse how the technological knowledge shared by a community of practitioners shift" (Laudan, 1984, p. 5).

The technological communities are made up of practitioners (engineers and technicians) that work within a defined technical discipline and share a common background formed by their education and training.

Of particular importance to the process of knowledge accumulation are the traditions shared by such a community of practitioners.

The traditions function as a filter that help the technicians select the problems that are potentially solvable by technical means and which also lead to further development of the technological knowledge of the communities.

Within the knowledge perspective one can speak of a path of knowledge accumulation when the problems that give rise to new knowledge are defined within the limits set by the traditions shared by the practitioners in a community. Such a process of development will be both limited and coherent in the sense that new knowledge builds on prior accumulated knowledge.

Common to the knowledge and artefact perspective on paths is an emphasis on the coherent and ordered manner of change. The following paths are defined in accordance with the artefact perspective as incremental changes in a product or a production technique. It is, however, argued later that such changes are strongly influenced by the process of knowledge accumulation in technological communities.

From the perspective of gaining insight into technological variation and development, the various ways of defining paths of incremental changes are not as such interesting. What is of far greater interest is the reasons that are given as to why technological development follows a path.

9. The emergence of technological paths

Dosi and Orsenigo (1984) have suggested that the emergence of paths (defined as coherent patterns and ordered behaviour) are related to the nature of learning and of specific institutional set-ups governing decisions and expectations, both of which work ex-ante relative to the market selection.

In an economic environment, where innovations are path dependent, the technological change process may be characterised as largely self-organising in the sense that order in the change process is the 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".*

Paths, however, are the outcome of both ex-ante and ex-post selection as the new technologies are introduced on the market.

The criteria by which the market selects technologies is equally important for understanding the direction of technological change, since only the technologies selected by the market shape future opportunities for development.

It then becomes important to consider how the selection criteria change as technological development proceeds.

Based on the theories of technological paths I believe it is possible to specify in more detail the self-organising mechanisms of technological development.

It may be that:

1) the dynamics that produce technological opportunities are of such a nature that opportunities emerge in a limited and coherent fashion from the knowledge and technologies already in use.

2) the path of incremental improvement in technological guidepost is sustained by institutions in the economic system that govern decisions and expectations.

3) the economic activities are of such a nature that natural selection favours technologies that represent only incremental improvements in prior technologies

The following two sections discuss in more detail how in particular the dynamics producing technological opportunities together with institutions in the economic system may provide a coherent and path dependent development ex-ante to market selection.

The interaction between the forces working in ex-ante market selection and the market selection is, however, only briefly touched upon in the discussion.

The dynamics producing technological opportunities

In this section it is discussed how the artefacts themselves together with the accumulated technological knowledge set a limit to the technological opportunities that can be identified at a given time as well as ensure a coherent development of opportunities over time.

The artefact and knowledge perspectives on paths have rather concordant descriptions of the technology internal factors that produce opportunities for technological development. In both perspectives, technological opportunities are seen as arising either from errors, repair problems and larger breakdowns or from emerging wishes for new features, facilities, and performance measures.

It is a general assumption within these perspectives that opportunities for further development do not emerge at random since paradigms *"..provide a relatively coherent source of mutations"* (Dosi and Orsenigo, 1988, p. 17).

Rosenberg (1988) uses the term "focusing device" to describe the dynamics in the technologies that constantly produce new problems and opportunities for technological development. He argues that complex technologies create internal compulsions and pressures that operate at the firm level and often within the components of the final products themselves.

In some technologies these focusing devices are subordinate to what Clark (1985) has called a hierarchical evolutionary path. The hierarchical path emerges because the physical structure and the interdependencies between parts makes some choices more fundamental and immediate to other choices.

"Physical interaction and the precedence of some parameters are likely to impose a hierarchical structure on the focus on innovative effort as it is reflected in successive generations of the product" (Clark, 1985, p. 241).

Sahal (1981, 1983) has specified how in particular *changes in scale* function as a focusing device. Changes in scale may be induced by technology external factors such as a change in demand that require an up-scaling in the production process. The scaling process gives rise to a number of technology internal problems such as *problems of imbalance* between related technologies, such as: bottlenecks, problems of timing different sequences of production, problems of adjusting the capacity of the interconnected production phases.

In general, he argues, a change in the scale of a product or a production process often requires the solution to:

1) problems caused by *uneven development* in the components of the technology
2) problems that arise because *new materials* are required
3) problems caused by a *more complex structure* in the technology.

These technological problems can give rise to innovations that change the structure of the product or process, that introduce new materials or that combine different technologies into one new system with a more simple structure allowing for further improvements.

The process of *diffusion* may also give rise to a great number of opportunities for technological development, because the identification of defects on the initial versions of a product becomes possible with the accumulated feedback from users (learning by using; Rosenberg, (1982)). Quite often the diffusion of a product requires the product to be *fitted into the users "environment"*. In some cases this implies changes in the scale of the product. In the food processing industries, e.g., producers of machinery often have to alter the scale of a machine, because the users have different scales of production and different space requirements.

In other cases, technology may be applied in new situations, which requires an *adaptation to new requirements*. In the fish filleting production some of the firms use a machine to take out the bones and cut the fillet into specified sizes. The machine had been developed in the chicken industry and its introduction in the fish filleting industry required a number of changes in the original technique.

Problems that give rise to developments may not only come from within the product and processes. Constant II (1984) has pointed out that problems, which he calls *"presumptive anomalies"*, are identified *"when scientific theory predicts either that the conventional technology will fail under some projected condition, or that an alternative technology would do a much better job"* (p. 31) The turbo jet is an example of a solution that was developed, not because the piston engine failed, but because the science of aerodynamics suggested that high-altitude, near-sonic flight would require an alternative to the piston engine and the propeller. In the case of the turbo jet engine, the problems identified by scientific theory did not have a solution which was within the path of development that characterised the industry for piston engine plans.

Based on a case study of the American auto industry, Abernathy (1978) developed the following typology of four process innovations, somewhat different from Sahal's.

1) Introducing *new process capabilities*, such as machines, that can perform different sub-tasks in the production process. There are several examples of such developments in the food industry as well. In the bread industry some firms have introduced a microwave oven which represents an improvement in the sterilisation technique.
2) *Organising the process*. This innovation often results in a change from batch to continuous production. The change from batch fermentation of levant to continuous fermentation in the bread industry is an example of such an innovation.

The two types of innovation take place in the early phases of an industry. In subsequent periods the individual process capabilities, and the overall process configuration, can be refined through innovations that make better use of information such as:

3) *Innovation in information and control systems* that refine and integrate the overall

process configuration. In, e.g., the bread industry much of the development effort aims at developing methods to control the process and measuring what happens to the dough as it passes different stages of production. An equivalent pattern can be seen in the fish filleting industry, but here much more emphasis is given to the control of the employees rather than product quality.

4) Innovation that *improves the overall process as a system*. The physical (and in the food processing industry biological) problems of scaling often fall within this latter category.

It is important to note that technology internal focusing devices, such as scaling problems, may dictate the technological opportunities within each of these innovation categories, but that *the progression* from one to another cannot be understood, unless technological uncertainty and the *competitive environment* are incorporated in the analysis.

In his analysis of the American car industry Abernathy shows how innovation and competition work together and shape the technological progression from one category to another.

The progression from one category of process innovations to the next has strong implications for the *relative importance* of technological opportunities in the *product* vis-á-vis the *process.* In the early stages, when the production process is more undefined, the opportunities mainly lie in improving the functional characteristics of the product, whereas in the later stages, when the production process becomes more integrated, the opportunities shift toward improving the efficiency in the production process and adapting the product to the process.

Abernathy (1978) also found that as the auto industry matured the production process imposed restrictions on the opportunities for product development. These restrictions shifted the attention away from improvements in the overall configuration toward adding more and more components to the car. On the one hand it expanded the opportunities for product variation. On the other hand, the interdependence between different components created a problem of co-ordination.

To sum up, technological problems occur in the design process - where technicians solve scaling problems or in the diffusion process - where user-feedback permits a better understanding of the defects in the initial version of the product (Writhing, 1984).

From the above presented arguments, it seems that the opportunities for technological development are constrained by the amount of problems that arise in technologies used by firms in an industry.

Abernathy's analysis of the auto industry indicates the opportunity for product and process development changes over time as the industry matures.

So far, the opportunities have been described as more or less given by the characteristics inherent in the artefacts. This is incorrect, since focusing devices *"..call attention decisively to* *the existence of problems, the solutions to which were within the capacity of society at the time"* (p. 123) as emphasised by, e.g., Rosenberg (1988). And, as further argued by Dosi and Orsenigo (1988), central to the technological development process is the process of technological learning.

Accumulation of new knowledge takes place as the technicians solve new technological problems. The actual manner in which the technological problems are identified and selected is therefore of great importance to the technological learning process. According to Laudan (1984) and Constant (1984), the tradition of technological communities play an important role in this process, because they function as a filter that selects the problems which have a higher chance of being solved by technological means.

The traditions contain heuristics or methods for problem-solving and criteria used for judging new technologies.

In some communities heuristics can be simple rules of thumb, whereas they in others are well developed methods that show engineers and technicians the road to possible solutions. Problems, where solutions are within the reach of the historically developed heuristics, will have a bigger chance of being solved.

Another important activity in the technological communities is to judge the technological solutions. This judging always takes place by comparing a new technology to other technologies. Where a technology is developed within the traditions of a community, it is much easier to judge the technology.

Summary

The arguments presented in this section strongly support the view that opportunities are not created at random, but within limits defined by a technological paradigm.

At any point in time the accumulated knowledge together with the nature of the processes and products in use set a limit to the opportunities that can be identified. The progress along a path (or trajectory) is irreversible and coherent, as the identified opportunities are products of prior technological development.
Paradigms encompass both the idea that technologies as such, together with the accumulated technology-specific knowledge and traditions of scientific communities, set a limit to and indicate the direction of change in a specific product or production process.

Based on this concept, one would expect a technological development process that was determined by:

1) incremental improvements in an artefact in accordance with the focusing devices transmitted in the artefact and
2) the development of new knowledge that falls within the limits of the traditions in a

community.

But one can ask if "the dynamics of technological opportunities" within a paradigm would produce a path of development at the level of an industry. In fact, they could but as both Sahal (1984) and Abernathy (1978) have pointed out, only after a dominant design approach or a guidepost has emerged.

In order to fully comprehend the phenomenon of paths at the industry level, one must also understand how the guidepost emerges, and how a path of incremental improvement in a technological guidepost is sustained by institutions that themselves are partly a product of the technological development process. This is the subject of the following section.

The role of firms and institutions

In this section it is argued that the path of incremental improvements in a technological guidepost is strengthened by the "positive consequences" for the individual firms by developing within the limits of the guidepost relative to developing alternative design approaches[5]. As firms "enter" the path, they become locked into it by their own investment in routines, learning and capital.

The process of technological development at the industry level is then shaped by the interaction of 1) developments in regimes - guided by such institutions as communities and techno-economic paradigms and 2) developments in configurations - guided by routines in firms.

Changes in terms of competition that follow from change in the individual firms' activities within such a path may then be met by vertical specialisation in a chain of production. The vertical specialisation increases the firms' dependence on investments and learning undertaken by suppliers, customers and other complementary agents.

Institutions[6] (such as techno-economic paradigms) may emerge as solutions to the problems of dealing with the complexity and interdependence in such a chain of vertical specialised producers. But at the same time these behaviour-shaping institutions may also influence the *direction of technological development.*

How institutions shape technological development

The important question in the context of this paper is how the decision routines and criteria of

[5] It should be made absolutely clear that the existence of a dominant design can not be explained with reference to these future non anticipated consequences. But these "positive" consequences can explain why the dominant design - once it has emerged - maintains a strong position as an "evolutionary attractor" (Van Parijs, 1981) in an industry.

[6] The term "institutions" is used very much in Dosi and Orsenigo (1988) as *"..all forms or organizations, conventions and repeated and established behaviors which are not directly mediated through the market"* (p. 19).

firms and institutions shape or strengthen a path of technological development.
Institutions and uncertainty are closely linked, as expressed by Dosi and Orsenigo (1988), claiming that: "*uncertainty necessarily implies institutions"* (p. 19), and uncertainty certainly is a dominant feature of technological development. Kline and Rosenberg (1986) go so far as to say that: *"the central dimension that organises innovation, if there is one, is uncertainty"* (p. 294).

Uncertainty may arise because the technologies themselves are *complex,* or because both technological success and market success depend in an *unpredictable* way on the decisions of many interdependent agents. From the part of the individual *firms this decision situation* is characterised by imperfect information, limited information processing capacity and the lack of understanding of means end relations.

With this amount of uncertainty, development decisions will not be based on maximisation criteria but on the decision makers' subjective understanding of the technological and market possibilities that are shaped within the limits of bounded rationality.

In fact, such *institutionally constrained* behaviour may be preferable to a more unstructured behaviour, as Heiner (1983) has pointed out:

"The existence of a permanent gap between the "competence" of the agents and the difficulty in selecting the most preferred alternatives.. is such that the restriction on the number of allowed alternatives (i.e. the "routinisation" of behaviour) may well increase the chance of "correctly" selecting the action at the right time relative to the chance of "mistakenly" selecting it at the wrong time" (Heiner, 1983, p. 565; quoted in Dosi & Orsenigo, 1988, p.17).

Routines and world view in firms and other organisations play an important role in shaping the technological development process, since they direct the behaviour in some directions rather than others, but before taking up the discussion of how institutions and firms shape the path of technological development, a clarification of the locus of technological development is called for.

On the one hand, e.g., Abernathy (1978) and Abernathy and Utterback (1975) describe a process of technological change shaped by innovative activities in firms[7] and competition between firms.

The stimuli to change arise partly from the market - in particular the competition between firms - partly from within the firms. In fact

"the characteristics of the innovative process and of a firm's innovation attempts will vary systematically with differences in the firm's environment and its strategy for competition and growth, and with the state of development of process technology used by a firm and by its

[7] Actually Abernathy has the productive unit as the unit of analysis. The productive unit is *"a general production process that is located in one place under a common management to produce a particular product line."* (Abernathy 1978, p. 48).

competitors" (Abernathy & Utterback, 1975, p. 640).
On the other hand, Constant (1984) and Laudan (1984) argue that the locus of technological development is the *technological communities*. The firms themselves - their organisation and economic and social criteria - only serve as external constraints, or as internalised values or imperatives, but they do not drive the process of technological development. The "success" and the development of the firms are not even contingent on the success and development in a community. Firms can change the core of their technologies whenever new communities emerge that are capable of producing better solutions.

The communities direct the process of technological development since they embody the knowledge, the search heuristic, the historically developed traditions and criteria for choosing between new technologies.

To a large extent these routines and capabilities are characteristics of a technological community rather than of individual firms. In fact, they are not even characteristics of an industry *"since one particular industry may employ many different traditions of knowledge, and since different traditions of knowledge may crop up in a variety of industries and organisations"* (Constant II, 1984, p. 12).

But, whenever an industry is dominated by one tradition, the firms in that industry will exhibit great homogeneity of practice across the industrial sector, but it does not imply that the firms develop identical products or production processes: *"Hondas and Oldsmobile are varieties which represent "fine tracking" of that environment"* (Constant II, 1984, p. 38).

Metcalfe and Gibbons' (1989) concepts of *"technological regimes"* and related *"design configurations"* show a way out of this conflict on the locus of technological change. By means of these two concepts I believe that it is possible to understand both the role of communities, and of firms in shaping the development process at the industry level.

Metcalfe and Gibbons (1989) define *technology* as an *artefact* with a revealed performance and its *corresponding knowledge base*. The firm as an organisation bridges these two dimensions of technology. In Metcalfe and Gibbons' words the role of the firm is to: *"articulate a knowledge base to design and implement a particular level of revealed performance."* (p. 154).

Both the knowledge base and the artefact as such exist within a structure of regimes and configurations.

Design configurations are defined as:

"A design configuration is a particular set of facts, hypotheses, operating procedures (know-how and know-what), and design parameters that enable energy and materials to be translated into products and processes with a particular physical configuration and embodying a particular level of revealed performance".

A single-product firm encompasses one design configuration, while a multi-product firm

encompasses many different design configurations.
The knowledge base and artefacts which make up different design configurations often share a large number of common characteristics. Metcalfe and Gibbons call such collections of design configurations a technological regime:

"The regime defines the core knowledge base for the set of design configurations, a core which is shared by all the firms in the regime and which set boundaries to the productive activities which can be undertaken by any of the firms involved (from Richardson, 1972)" (p. 161).

The core of technologies within a *regime* may have its own locus of change in the *technological communities*, while technologies within *configurations* have their locus of change in the *individual firms*. Development in configurations may alter the regimes and vice versa.

At the level of *design configurations*, technological developments may take place, when firms develop processes and products with higher levels of performance. In the process, firms accumulate technological knowledge in design, in production and in interaction with users, being technology-specific and specific to the individual firm and its users. Some of this knowledge may not be codified or may even be tacit and consequently not transferable. But some of the knowledge may be firm-specific only because it is kept secret.

Based on the following arguments it is reasonable to believe that the development of technologies within configurations follows a path of coherent and incremental improvements in the firms' process and product techniques.

First, the opportunities that the firms can discover depend on the *focusing devices* inherited in their technologies and on the knowledge accumulated from prior development efforts. This alone is likely to create an *irreversible and coherent development.*

Secondly, given that firms are bounded rationally, and that it is time consuming and costly to alter a complex, integrated system of technologies, it may simply also be a *better solution* or a more *economically feasible* one not to alter the structure of the overall technology system too much[8].

Thirdly, firms' *organisational routines and choice criteria* may further support such a development, because they are developed along with the developments in firms' technology.

Differences in firms' technologies, their users, their technological knowledge and procedural rationality could result in *a number of paths of development at the industry level*. And this is indeed often the case in the early phases of an industry's development - as described by Sahal (1984) and Abernathy (1978) - but, when in the course of development a *guidepost emerges*, the structure in the development process rises and the vast heterogeneity is reduced.

[8] Not only may the individual firm's technology be complex but as, e.g., Sahal (1984) points out the systemic character and the strong interdependence between the technology of users and producers may favour solutions to technological problems that represent only incremental improvements rather than a total restructuring of the technologies.

The guidepost or dominant design is a distinct artefact like the v-8 engine in the auto industry. Such a dominant design is often the outcome of a trial and error process (a reinforcement mechanism) in which well known design concepts are integrated and a process of diffusion in which the more workable solutions are favoured to less workable solutions.

Usually firms do not know in advance which design approach will be the dominant one in the industry. It depends in more or less unpredictable ways on complementary innovations, which coupled with changes in market preference, cause one approach to gain in preference over another (Abernathy, 1978)[9], and as pointed out by Clark (1985), consumer preferences for one design approach over another is often formed ex-post the introduction of the design approaches.

The emerging of a *dominant design* lends a more firm structure to the *hierarchy of communities* involved in development activities across an industry[10]. Put another way, a guidepost helps shape a *regime,* because it structures the communities within the industry.

The practitioners in the communities may be employed in different firms and research institutions, but since they share the same educational background the *communication between* technicians from different institutions is very much facilitated. Indeed, their knowledge is *community specific* rather than firms specific.

If these *communities* are the locus of technological development at the level of the regimes, then *regimes* develop when the community of practitioners solve problems that are either common to firms in an industry or that lead to improvement of the methods used by the communities[11]. The routines that shape this development are traditions, search heuristics and judgement criteria of the communities involved[12].

The dominant design does not only play an important role in shaping the regimes, it may also become a very stable *"evolutionary attractor"* (Van Parijs, 1981) that shapes the future evolutions into a self-sustained path, where standardisation of the product is followed by changes in the production process and changes in the selection environment.

Once the dominant design has emerged, its position as a stable "evolutionary attractor" may be strengthened depending on the *positive consequences* of developing within the limits of the

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[9] The dominant design is characterized by an nearly complete rate of diffusion in the industry. Only when the design approach does not fully satisfy the design requirements in all segments or when highly competitive approaches exist, will it have lower rates of diffusion (Abernathy 1978).

[10] Guideposts play a much more important role in industries where both technological development and user situation is characterized by complexity. In industries such as the fish filleting industry, where the product is simple and the market uncertainty low, there are no actual guideposts. But on the other hand in such an industry there is not much room for deviant paths of product development. There may, however, still be room for variations in the production process. But in such an industry - with little product variation - guideposts that structure the development in the entire chain of production into one path may emerge at the suppliers of capital equipment.

[11] Sometimes development in the regime may consist of the inclusion of other traditions or pure science (Laudan 1984).

[12] Technological paradigms(1988) have many institutional features in common with the technological communities that shape the development at the level of technological regimes.

dominant design relative to developments in other designs.
Some of the following arguments may illustrate why developments within the limits of the dominant design may be *less costly than alternative paths:*

Firstly, the dominant design represents a workable solution to technological and market problems reducing *the uncertainty* in both these dimensions. Since the cost of development is positively correlated with uncertainty, it may be less costly to develop within the limits of the dominant design.

Secondly, there may be *economies of shared experiences and learning at the level of regimes*, which effect the development cost.

Thirdly, on the market side the dominant design may reduce the cost of *adapting the product to different users*. And actually the customers or users may prefer a more standardised solution, since it makes their investments in new work methods, upgrading of production skills, modifications in product design and plant layout (Sahal, 1984) less specific and less prone to create transaction costs.

Fourthly, once a dominant design is established in an industry, the *suppliers* would most likely direct their development efforts towards improving the inputs and capital equipment they supply to "fit" the dominant designs in the industry. The producers that do not converge toward the dominant design may have *difficulties in finding high quality suppliers* or even suppliers at all. They may therefore be forced to take on a larger part of the production of input themselves.

Given that firms have limited resources and time, and that it is more costly and more risky to develop alternative solutions, it is possible that reinforcement mechanisms or natural selection may bring about a convergence in the firm's development efforts[13].

But as more and more firms take on a production that is in line with the dominant design, the *competition changes* from competition on product performance characteristics to a competition on price. Abernathy (1978) and Abernathy and Utterback (1978) have described how this change in the selection environment stimulates changes in the production units toward an integration and automation of the production process.

In fact, Abernathy - in his analysis of the American auto industry - argues that:

"The important economic effects of a dominant design afford a degree of enforced product standardisation, so that production economies can be sought, and provide a bench mark for functional performance competition, so that effective competition can take place on the basis of cost as well as product performance." (Abernathy, 1978, p. 75).

In a very brief presentation of Utterback and Abernathy's "dynamic model of process and

[13] But it is also possible that for some firms the orientation toward the dominant design can be explained as intentioanl.

product innovation" (1978) the sequence of changes in an industry is as follows:
With the emergence of a dominant design, a *standardisation* of the product makes possible an integration and automation of the production process, but in return these changes drastically increase the cost of changing the product.

This *tight integration of the production process* therefore further structures the development process within the individual productive units. From then on product innovations most often consist of adding components with new functional characteristics (Abernathy, 1978). Clark (1985) characterised this pattern as one where the number of design approaches in a functional area of a technology narrow down to a few with new ones emerging in other dimensions.

Once the product is standardised and the production process is geared for mass production throughout an industry, *price* becomes a much more important *selection criteria* relative to product performance.

The *strong price competition* further stimulates cost-reducing changes in production, and increased division of labour and specialisation in the production.

Depending on the production *and* transaction costs encountered by the firms, these attempts may results in the emergence of a supplier industry for special material and technology based capital goods[14].

This pattern of change indicates that - as a result of the dynamics of technological development and competition - the supplier industries may play a much more important role in shaping the technological development. This is indeed what Abernathy (1978) observed in the American auto industry.

As the opportunities for product development from the part of the end-producers became more and more limited, new innovation in components originated outside the industry in the supplier industries. Developments in these industries were, however, constrained by the hierarchical structure of interdependence in technology since:

"Each level in the hierarchy competing alternatives have implications for subsequent decisions, but the choice at the apex has ramifications throughout the hierarchy" (Clark, 1985, p. 234),

where the dominant design (at the apex) impose a number of limits to the technological development in the supplier industries.

[14] On the production side the standardization of the product in accordance with a dominant design should create opportunities for scale economies and specialization advantage in learning (both in production, and in development functions).
On the transaction side it is somewhat more difficult to specify the effects of a dominant design. On the one hand the integrated production process gives rise to demand for specialized capital and input goods resulting in increased search costs and large investments in specialized assets. According to Williamson (1975) these changes could raise the transaction cost. On the other hand the performance criterion for product and process designs is much more well articulated and less costly communicated to the suppliers (Abernathy 1978) leading to a reduction in the cost of communication (and in some cases also in controlling the quality of the goods).

But the *complexity and the strong interdependence* between the product and the production process creates a need for *co-ordination* in the whole chain of production as exemplified by this quotation from Abernathy's study of the auto industry:

"The automobile producer manages a portfolio of different productive units whose product are the components of the final product - the car. The present general model specifies the set of trade-offs that affect each productive unit, but individual units cannot be managed independently; rather, the entire portfolio must be considered as a whole in order to realise both short-run and long-run competitive advantages" (Abernathy, 1978, p. 164).

How is the hierarchy of supplier industries held together and how are developments co-ordinated throughout the chain of production? At one extreme a hierarchy is established and co-ordinated by means of a *vertical integration* of ownership at the other extreme, the hierarchy may be a product of *natural selection*, which only favours those firms that "fit" the limits of development set by the dominant design.

But in between these two extremes, there is the possibility that *behavioural shaping institutions* may arise as a response to the externalities and create co-ordination between the firms[15]. As Andersen (1991) argues:

".. the concept of techno-economic paradigms should not only be considered as means of co-ordination among the producers of technological knowledge but also as means of co-ordination between groups of producers and users of specific types of artefact, as shared specifications of typical interfaces between the two parties" (p. 119).

The *techno-economic paradigm* defined by Andersen (1991) is

".. a mutually accepted and stable specification of the interface between producers and users of a complex type of artefact. This artefact or commodity is mainly understood in terms of major functions vis-à-vis the users, but normally a few specifications of material tex. are also included. All other information of, e.g., the production process of the artefact or its users is irrelevant to the interface" (p. 128).

The techno-economic paradigm provides *a stable interface between* users and producers easing co-ordination in a chain of production because it delimits and reduces the necessary flow of information through the interface between the firms.

How the interface between the two parties is shaped depend on the *"principle of commodity abstraction"* and on *"the principle of interactive learning"* between users and producers (Andersen, 1991).

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[15] Coordination between the firms may then be explained either as intentional (the firms recognize how the externalities function and adjust their development plans in accordance with expected effects) or as the outcome of an reinforcement mechanism (where firms adjust their development routines as a response to a trial and error process).

The process of commodity abstraction (the development of a product concept on the user side and a shared definition of the relevant performance features of the product in the interface between user-producer) may be perceived as an interactive learning process that is strongly intertwined with emergence of dominant design on the producer side (Clark, 1985).

On the *user side* the understanding of the product is a result of learning and problem-solving on the part of the individual users as well as communication between them[16]. With a new product, the learning process is not simply a matter of finding out which technical features satisfy a set of objective, well-known needs, rather it involves a more fundamental understanding of ones needs as well as of how different competitive offers may be evaluated in the purchase decision[17] (Clark, 1985).

With the emergence of a *product concept* follows also a much sharper definition of the performance characteristics on which a concrete instance of the commodity can be evaluated. The concept is also of great importance in shaping the users' criteria for selecting between rival products, because with a better understanding of ones needs and the potential in a product the differences between a product and its rivals become sharper.

The product concept that emerges among the users of a product may be expressed in terms of a *commodity abstraction* in which the name and a few parameters are sufficient to describe the artefact in question.

But the principle of commodity abstraction is more than a *shared understanding* of the product, as a concept is also an artefact which is *reproducible* in such a way that "that the buyers' accumulated knowledge of the characteristics of the commodity-type will more or less hold for the next instance of it" (Andersen, 1991, p. 131). The buyers, therefore, need not spend time and resources on learning how to alter the product concept for each individual artefacts.

Vertical disintegration in the chain of production becomes more likely when a basic design (dominant design) of an artefact is in accordance with "the principle of commodity abstraction", because then both parties have *lower costs of communication as well as lower costs of interactive learning*. Less information is needed in the transaction and learning process (learning-by-using; Rosenberg, 1982) since the communication is confined to performance measures in defined performance criteria.

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16 Clark (1985) emphasises that "The pattern of innovation, the kinds of design changes introduced and their timing and sequence, not only depend on the technical alternatives but on the product and the evolution of customer requirements" (p. 236).

17 Building on theory of customer choice in the marketing literature, Clark suggests that consumers' learning process has two critical aspects. The first is a process whereby the unfamiliar product is grouped with other known product concepts. The second is distinguishing the dimensions of the product that differentiate it from this group. If the new product is a new kind of bread like, e.g., the pita, this process will involve first placing the pita in the category of breads. Having done this the consumer will locate the differences between a pita and ordinary white bread such differences would be taste, texture, shape, ability to interact with other foods (In what dishes can it be used).

The "positive consequences" on, e.g., the cost of communication and learning may explain the institutionalisation of the interface into what Andersen calls a techno-economic paradigm[18].

What is interesting in relation to the technological path of development is that the emergence of a techno-economic paradigm with its stable interface starts the process of *"normal" technological development* on both the producer and the user side where:

"To the users the relevant problems, procedures and knowledge base concern the relation between the price and the performance parameters which may be part of the interface. To the producers the relevant problems, procedures and knowledge base concern the efficient production of the given artefact/commodity and the profits derived from improving it according the performance parameters" (Andersen, 1991, p. 128).

The techno-economic paradigm does not only economise on transaction costs; it also helps *co-ordinate the development efforts of diverse firms in the chain of production*.

Through the process of *commodity abstraction* the users continually develop a better understanding of the potentials of the product and in which directions they want the product to be developed. This ease of defining the users' needs should facilitate individual firms' adaptation in a chain of production[19]. The "principle of commodity abstraction" then implies that their wishes may be expressed in terms of changes in some given performance criteria of the product (see also Sahal (1984) for an in depth discussion of the role of *performance criteria* in the development process)[20].

Summary

In this paragraph it was discussed how firms, communities and techno-economic paradigm shape development within regimes and design configurations, respectively. It was argued that

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18 Andersen (1991) argues that the techno-economic paradigm provides a rather stable interface between the users and the producers that arise as a response to the problems of dealing with the complexity of interdependence between the technology of the user and the producer:

"The basic problem is one of coping with complexity: a user might question the construction of one, or a few of the inputs into his production process and might be involved in the development of an input product with new characteristics. However, the principle of procedural rationality tells us that in a complex intra-and interorganizational network everything cannot be changed at the same time without creating chaos (p. 128).

The persistence of such a stable interface may then be explained with reference to its positive effects on such costs as: 1) search costs, cost of measuring and evaluation different alternatives by users (Bazel, 1982) 2) producer costs for obtaining information on user preferences. Or it may be explained by the negative effect (or sunk cost) on the individual firms and their customers, if they depart from the interface. Once consumers have invested time and energy in "defining" a product concept, they may be less willing to try on new types of product they cannot as easily evaluate. On the producer side sunk cost may be found in specialised equipment, skills, and knowledge.

19 The incentive of firms to know more about user preferences arise from their rivalry, since the best way of "minimizing" the impact of rivalry is by obtaining a better understanding of customer requirements and how their product design fit these requirements (Clark 1985). The rivalry on the other hand also imposes a strategic uncertainty in product design, because firms cannot know how the rival's product influences their own product success.

20 Andersen (1991) points out that "the principle of commodity abstraction" and "the principle of interactive learning" are opposing principles for designing the interface. I somewhat disagree but interpret the "principle of commodity abstraction" as also a means of reducing the cost in interactive learning. I agree that the principle of commodity abstraction will limit the interactive learning to performance measures included in the abstraction

when a dominant design emerges in an industry, it then creates a number of externalities that influence routines and choice criteria employed by firms in an industry as well as in the whole chain of production. The pattern described in the "Dynamic model of process and product innovation", (Utterback & Abernathy, 1975) e.g., indicate that the externalities in the industry may change over time, as the industry becomes more dependent on the supplier industries. This may in turn produce new institutions such as techno-economic paradigms that help direct the future developments in the industry.

10. Technological paths and natural selection

The review of the literature on paths indicates that order is partly the result of factors such as the dynamics producing technological opportunities and partly by the institutions that ensure coherence and limits in the technological variation ex-ante the market selection. New technological solutions do not emerge totally at random but they are linked to the previous technological designs and are limited by the accumulated technological knowledge and the quality of search and development heuristic developed in the industries. As a dominant design emerges, the firms and institutions in both the industry and the supplier industries will concentrate their development efforts around this design.

With a limited set of technological opportunities to choose from, the technological variety in an industry is reduced. The path may then be strengthened or weakened by the natural selection work on this limited technological variety.

The path is strengthened by the natural selection whenever the direction of technological development produced by the ex-ante factors is consistent with the criteria of selection.

It is, however, reasonable to believe that in periods with normal technological development, it is a case of biased variation in the sense that definitions of technological opportunities are influenced by the criteria of selection.

The bias comes into existence because:

1) the selection criteria employed by the users are themselves a product of technological development as argued by Clark (1985). As the "product concept" and "commodity abstraction" emerge, the criteria for selection becomes much more homogeneous and also more easily identifiable and communicated to the firms.

2) firms and institutions that govern technological development are capable of both learning and to some degree also of anticipating future selection environments. In industries where the selection environment is rather stable in longer periods of time, the bias will be stronger than in industries which change more rapidly.

Finally, the selection environment could in itself create a path of technological development without any ex-ante forces working on the variation. The paths then emerge because the criteria for selection are rather homogeneous and because the natural selection favours only those technological solutions that are sufficiently close to the technological solutions already in use.

It does, however, seem highly unlikely that paths are solely shaped by natural selection forces: that there are no ex-ante factors that reduce the possible variation.

Appendix

A general description of technological opportunities

Technological opportunities are the *perceived possibilities* for improving production processes and products at a given time. The opportunity set therefore depends both on changes in perception as scientific and the technological knowledge increases and in changes in the technologies, which may give room for new improvements.

It is difficult to find a general way to describe the technological opportunity set which encompasses both these dimensions of changes in the opportunity set. Clark (1985) and Metcalfe and Saviotti (1984) have offered two distinct but related contributions which serve as an inspiration.

Clark's concept of design hierarchies offers a framework for describing the evolution of product technologies, but it may also be used as a frame for describing the opportunity set for improving products in an industry a given time. Clark examined the interaction between design decisions in engineering and the choice of customers in the auto and semi-conductor industries.

The model therefore encompasses both the consumer and the product technology side.

The two processes; "the logic of problem-solving in design" and "the formation of a product concept" impose a hierarchical structure of the evolution of technology" (p. 236).

At this point a more detailed description of the process that determines the direction of change will not be given, as it is not relevant for a static description of the opportunity set.

Central to the opportunity set is, however, the description of the design hierarchy which delimits the opportunities at a given time.

At the apex of this hierarchy is the dominant design of a product such as, e.g., a car. This product can be identified in terms of its basic functional parameters such as speed, steering etc.

Each parameter pertains to a functional domain (in the terminology of Saviotti and Metcalfe) of product technical characteristics. Within each of the functional domains many alternative concepts may exist for technicians to choose from. These alternatives make up the technological opportunities for solving different functional problems. The opportunities are, however, constrained by the strong interdependence in choice among ways of improving a product.

Saviotti and Metcalfe's framework for the analysis of the evolution of technology is based on a three dimensional characteristics' description of product technology.

The three dimensions are:

1) the *product-service dimension* representing the needs/wishes that the user of the product may have. The product-service dimension does not only contain main service characteristics that are valued because of their benefit to consumers. The dimension can also include complementary service - and externalities - features that one wants to minimise.
2) the *product-technical dimensions* which are the technical features incorporated in the product in order for it to produce the service functions.
3) the *process-technical dimension* entails such elements as the material and the operations performed on them (shaping, mixing, assembling technology); the forms of energy required and their methods of transmission (labour or machine); the various skills required by the labour force and management.

I believe that the general idea behind the three dimensions of changes can also be used as a means of describing the opportunity set in an industry at a given time.

The opportunity set can be interpreted as the possible changes in the three mentioned dimensions. At a given time the opportunity set is constrained by the interrelations between changes in the product-service dimension, the product technical dimension and the process technical dimension.

On the product-service dimension alone the possibilities for changes lie in a) continuous changes of the absolute values of different service characteristics. (An example from the bread industry of a continuous change would be an increase of bread's keeping qualities from one week to two weeks) b) a non-continuous change in the mixture or balance of different service dimensions (exemplified by, e.g., different priority to health vis-à-vis keeping qualities of bread).

Parallel to the opportunity in the product-service dimension is the opportunities in the process-technical dimension. A continuous change in this dimension is, e.g., the amount of preservation put into the bread, whereas a change in balance of components would be changed in the composition of the dough.

The idea behind the framework may be more easily understood using an example from the auto industry. In the table below Saviotti and Metcalfe have listed the technical and service characteristics of a car.

Saviotti and Metcalfe's framework resembles that of Clark by stressing the importance of both the technological features and the consumer in determining the direction of technological changes. It differs in two respects. First it does not have the hierarchical perception of the opportunities, which Clark emphasises so much. Secondly, it also incorporates the technological progress in processes. The latter is a very important aspect in the food processing industry, because in this industry the opportunities for major technological improvements are often in the production processes, and because changes in products are also to a great extent dependent on changes in the production process.

Table AA: Marple's ducts and valves problem

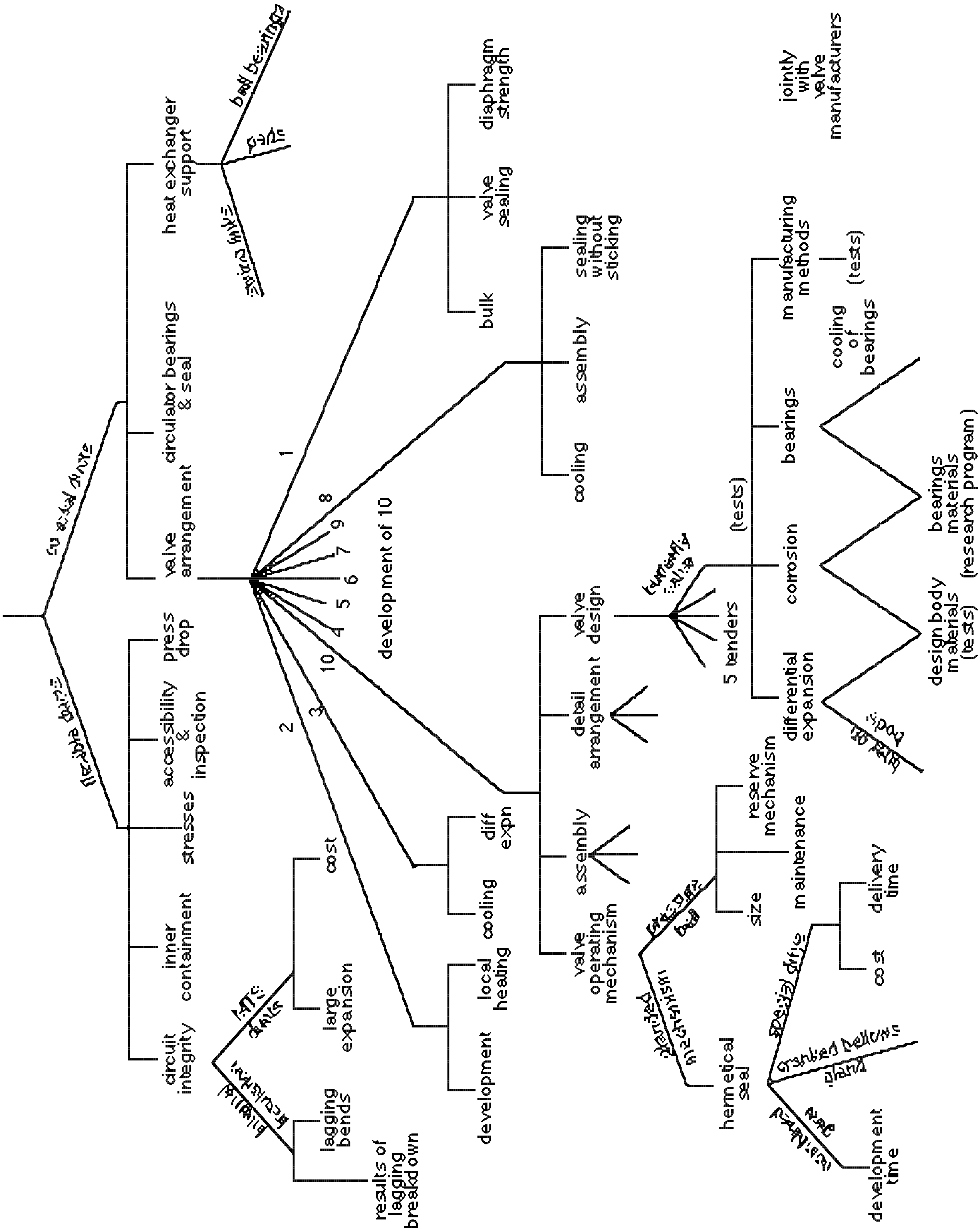

Table AA: Product characteristics - motor car

Technical characteristics		Service characteristics		Economic environment (costs)
Engine	Type	Main	Speed	Purchase
	Size	services	No. passengers	Maintenance
	No. Cylinders		Luggage space	Running Costs
	Bore			Depreciation
Engine	Stroke	Complementary	Ventilation	
	Compression ratio	services	Comfort	
	Carburettor		Radio	
	Injection		Instruments	
	Position			
		Externalities	Pollution	
Transmission	No. gears		Noise	
	Syncromesh		Space occupied	
Transmission	Automatic		Danger to	
	Semi-automatic		occupants	
	Clutch		Danger to other	
	Driving wheels		people	
Braking	Disc/drum			
system	Power braking			
	Circuits			
Suspension	Independent			
	Shock absorbers			
	Leaf springs			
	Hydropneumatic			
	No. positions			
Body	No. volumes			
Electrical system	No. doors			

Source: Metcalfe and Saviotti, 1984

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MAPP publications

MAPP working papers

No. 1: Grunert, K. G. & Baadsgaard, A. *Market-based Process and Product Innovation in the Food sector: A Danish Research Programme*, January 1992.

No. 2: Thøgersen, J. *Fødevareinnovation og Emballage - Miljøkonsekvenser og Forbrugerreaktioner*, Marts 1992.

No. 3: Bonke, J. *Choice of Foods - allocation of time and money, household production and market services*, September 1992.

No. 4: Grunert, K. G. & Ellegaard, C. *The Concept of Key Success Factors: Theory and Method*, October 1992.

No. 5: Harmsen, H. *Determinanter for Produktinnovationssucces*, November 1992.

No. 6: Grunert, K. G., Nissen, L. & Wildenhoff, L. *Do Danish Food Companies Analyse their Competitors*, February 1993.

No. 7: Bech-Larsen, T.: *Overvejer forbrugerne emballagens funktions- og miljøegenskaber, når de køber fødevarer?* Februar 1993.

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MAPP conference papers

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Furthermore there are a number of project papers, which are not available to the public.

The Mapp programme consists of the following 15 projects

1. Strategic Planning and Innovation Capability in the Danish Food Sector
   Morten Kvistgaard & Kirsten Plichta, Copenhagen Business School; Lone Rossen, Biotechnological Institute

2. Innovation Capability as a Key Success Factor
   Klaus G. Grunert & Hanne Harmsen, The Aarhus School of Business

4. Definition of the Sales Potential for a New Food Product to be Launched on Home or Foreign Markets
   Anne Martensen & Lorentz Andersen, Copenhagen Business School

5. Primary Producers and Product Innovation in the Food Industry
   Villy Søgaard, University Centre of South Jutland

6. Controlling Processes of Production to Guarantee Process Characteristics Demanded by Consumers of Food Products: Paradigms and Danish Experiences
   Esben Sloth-Andersen, Aalborg University Centre

7. The Role of the Distribution System in Product Innovation
   Hanne Hartvig Larsen & Nick Norman Jensen, Copenhagen Business School

8. Prototyping in the Danish Food Industry
   Preben Sander Kristensen, Aalborg University Centre

9. Product Quality and Consumer Preferences: Assessing the Optimum Design of Food Products
   Kai Kristensen, Hans Jørn Juhl, Anne Bech & Erling Engelund, The Aarhus School of Business; Carsten Stig Poulsen, Aalborg University Centre

10. Product Innovation and Packaging in the Food Industry - Environmental Consequences and Consumer Reactions
    John Thøgersen & Tino Bech-Larsen, The Aarhus School of Business

11. The Consumer as Agent in Relation to Research and Development in Food Technology
    Erling Jelsøe, Birgit Land & Jesper Lassen, Roskilde University Centre

12. Households' Choice of Foodstuffs with Different Kinds of Preparation
    Jens Bonke, University of Copenhagen

13. The Cultural Dimensions of Food Consumption and the Implications for Strategy Formation and Implementation in Small and Medium-sized Danish Companies
    Dominique Bouchet, Josette Andersen, Søren Askegaard, Tage Koed Madsen & Per Østergaard, Odense University

14. Market Surveillance Systems for the Food Sector
    Klaus G. Grunert & Karen Brunsø, The Aarhus School of Business

15. Identification of Key Success Factors
    Klaus G. Grunert & Elin Sørensen, The Aarhus School of Business