INSTITUT FÜR VOLKSWIRTSCHAFTSLEHRE

der

UNIVERSITÄT AUGSBURG

New Developments in the Economics of Technology and Innovation

von

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Beitrag Nr. 64

September 1991

Volkswirtschaftliche Diskussionsreihe

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1. Introduction

Without any doubts the Economics of Technology and Innovation is nowadays one of the most important research fields in economic sciences. Reasons for this good standing are manifold. However, two of them seem to be of some more importance:

First of all, the so-called mainstream economics based on classical and Keynesian ideas run into a crisis because - besides others - the importance of technology and technical progress was badly neglected. Hence, a number of economists turn to theoretical concepts, where just these factors are in the very centre of interest. And here, we have, above all, to mention the name of Joseph Alois SCHUMPETER and his "Theorie der Wirtschaftlichen Entwicklung" (1912).

Secondly, by trying to figure out the current prosperity of the Western industrialized countries, there is no doubt that technology, technical progress, innovations, productivity and structural change have to be identified as core elements of the economic progress. To imagine daily economic life without technology is completely impossible. Before the turn of the century economic growth was mainly spurred by the increasing use of input factors as labour and capital (*Solowian Growth*) and increasing national and international division of labour (*Smithian Growth*). Today, however, the nearly infinite possibilities of technical improvements count by a significant degree to the process of growth and increasing welfare of societies (*Schumpeterian Growth*).

As to empirical evidence, the example of Japan is a very prominent one. Japan's rise to an economic superpower cannot be conceived of without the successful application and development of up-to-date technologies. And the East Asian "Tigers" seem to use the same track. Of course, also the success of the German economy relies besides other "ordnungspolitischen" fundamentals heavily on the innovative creativity of engineers, technicians and entrepreneurs. Consecutively, in our country new productions come into being, and this not only in the so-called high-tech-sectors. Other sectors, however, change quite differently: In some instances their importance is declining as e.g. in the traditional mining or the steel industry. In other cases industries try to conquer formerly intangible markets by offering substitutive and improved products. And, finally, there are sectors easily adapting to new technological conditions. A good example in this stance is the chemical industry[1], which due to the successful use of computer technology, developed from traditional mass production to flexible and highly specialized production techniques ("Chemotronics").

Technological improvements, however, are not only responsible for sectoral and structural changes in an economy but they are also the keys for success or failure of firms. Thus, the survival of competitive firms will depend heavily on their ability to generate new products or production processes. Therefore, technology increasingly becomes the constitutive - or better - strategic element of a firm's policy.

To create something new is one necessary requirement to be successful, a second one to preserve competitiveness is the adaption to changing conditions. This applies especially for firms within the service sector, e.g. banks and insurance companies.[2] Here survival in highly competitive markets cannot be guaranteed for without the successful mastery of up-to-date information and communication technologies. Failing firms will fall behind nationally and internationally. Thus, not without good reason do firms lay more and more emphasis on the management of technology and innovation and try to integrate it into the firm's strategic planning for the medium and long-run.

As already mentioned, orthodox theory failed to deal with such problems. Even today it is still argued that these factors are exogeneous to economic life and that economic agents have to adjust to it in one way or the other. The interesting phenomena are the adjusting processes and not underlying factors of disturbance - especially when they are found in the field of technology. Mainstream economists, whether they are inclined to Adam SMITH or to John Maynard KEYNES, render technology as a "black box" whose content has not to be considered any further.

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1 FREEMAN (1990).

2 See for example WIT (1990), DIEDEREN *et al.* (1990), BABA/TAKAI (1990).

We think it is not necessary to show that this view is antiquated and far from reality. We know - not only from natural sciences - that simple linear relationships do not bear the importance we assigned to them in theory. We are rather going to substitute them by complex and interdependent systems characterized by forward and backward loops. This all applies also for the interdependence between technology and economics.

In the following we shall present some basic ideas and core elements of the current state in the Economics of Technology and Innovation. Let us start with a short historical digression to Joseph Alois SCHUMPETER who is designated as spiritual father of this research field.

2. SCHUMPETER and the Theory of Economic Development

Already at the beginning of this century SCHUMPETER recognized that the guiding principal of economic development is the creation of something new. The 'new' he calls innovation which is the object of economic development. The entrepreneur creates the new and introduces it to the market. Thus, he is to be considered as the subject, the initiator or promotor of growth and development.

How does SCHUMPETER define innovations and what is the fundamental motive entrepreneurs are driven by?

SCHUMPETER defines innovations as new combinations which are economically successful. Explicitly he describes five cases:[3]

(1) New products or products with new qualities, called product innovations;
(2) new production processes, called process innovations;
(3) new markets;
(4) use of new raw materials and other intermediate products;
(5) introduction of new organizational structures.

The entrepreneur is seen as the person accomplishing innovations. He is able to perform something entirely new and to succeed on the market. His motives are

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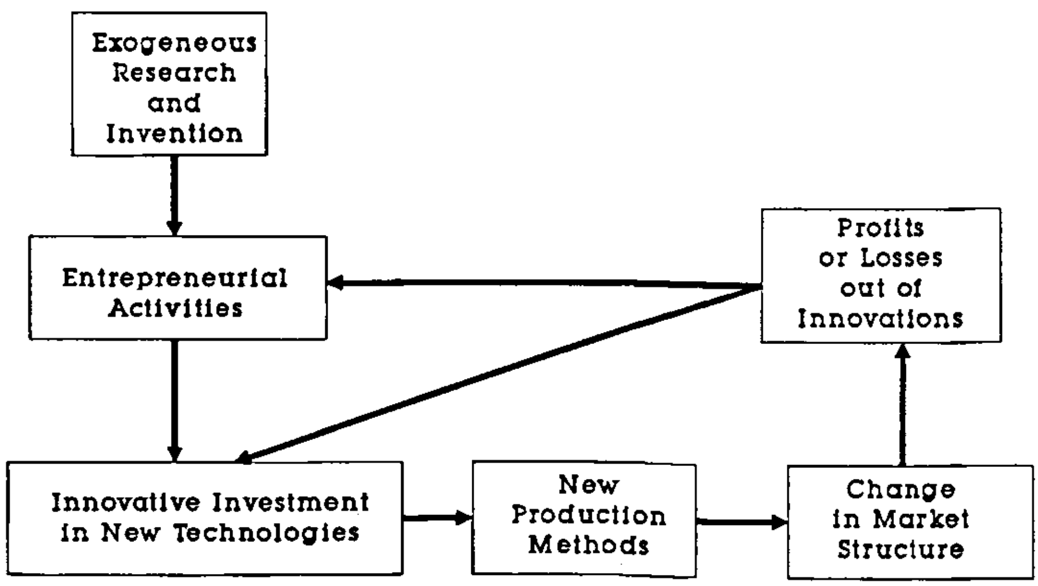
[3] SCHUMPETER (1912), pp.101.

manifold but to strive for profits is certainly a very forceful one. Thus, entrepreneurial activities are on the one hand exceptionally creative and on the other hand also a highly risky (ad)venture. In effect such activities always lead to the creation of something new and the destruction of some useless old. The SCHUMPETERian entrepreneur is thus engaged in a process best described as "creative destruction".

Hence, SCHUMPETER's entrepreneur is characterized by a special entrepreneurial instinct (animal spirits), i.e. he unconsciously knows how to act and which activities have to be accomplished and will be sucessful; he invests in new technologies and thus provides new structures of production. But also on the market he induces fundamental changes. He establishes a temporary monopoly enabling him to strive for so-called *quasi*-rents out of the innovation - at least temporarily. This model of the process of economic development is shown in figure 1.

Figure 1: Model 1



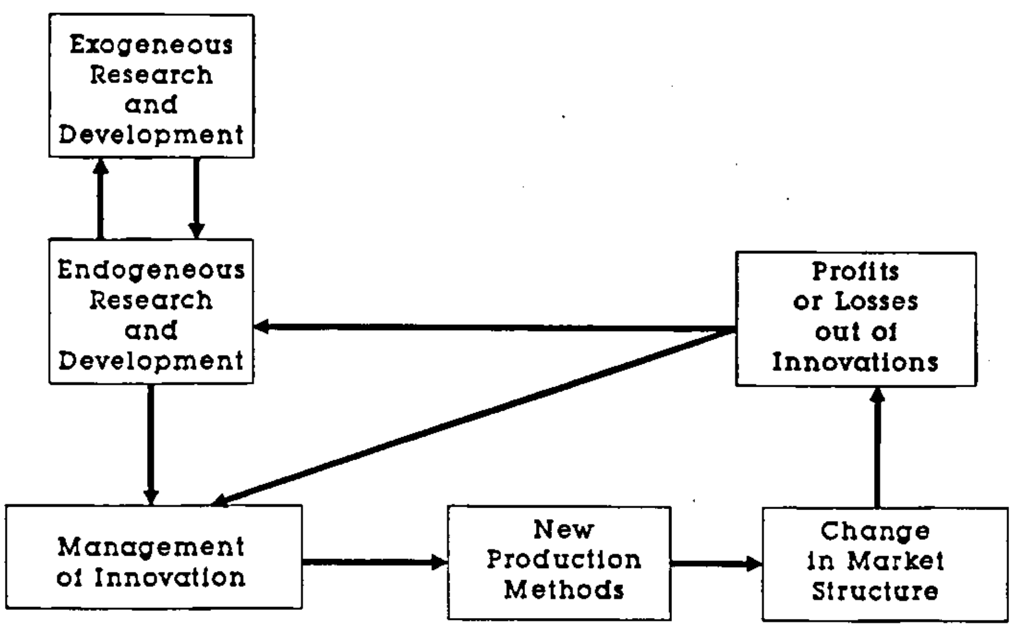
What we have to point out here is that the entrepreneur is only engaged in making new things marketable. He is by no means involved in the R&D process spurring invention. Thus, R&D-activities and the process of invention are to be rendered as entirely exogenous.

In all, these relationships show a very simple model of economic reality and we have to ask whether the early SCHUMPETER was right claiming that (a) the entrepreneur solely determines technological progress and that (b) R&D and invention is entirely exogeneous.

The huge research laboratories of IBM, Thomson, or Siemens, the increasing number of technology and industry parks, and of course, the MITI of Japan concentrating on innovation and technical progress seem to bear evidence that technological progress is accomplished in a manner totally different to SCHUMPETER's model of the entrepreneur presented above. Here, the function "entrepreneur" is substituted by a special organizational unit, and the systematic (re)search for new marketable devices stands for the entrepreneur's animal spirits. Therefore, the firms's size and thus the pattern of their organization and management may also influence innovative behaviour.

SCHUMPETER himself deals with this question in his "Capitalism, Socialism and Democracy" (1942) and there he presents a second model suitable for a large firm. Figure 2 shows the principle design.

Figure 2: Model 2



This model differs from the first one in two ways. First, in large firms we usually do not find single entrepreneurs led by animal spirits than rather all innovative activities are planned and accomplished by larger organizational units and designed for the medium and long-run. In the last years the so-called "Management of Innovation" has become an important strategic variable in many fields and within the research of business administration it is one of the most prominent topics.

Second, scientific and technological progress is accomplished within the firm, it is endogeneous. Of course, there exist close cooperations to external research institutions, but what is important here is to endogenize technical progress. This implies that firms try to "produce" systematically new and useful knowledge where the feature of market success loses its weight. However, the motive proper for innovations to seek for profits still holds true.

Now, which of the two models presented above has more explanatory power?

This is a question industrial organization has discussed intensely. It is broadly agreed upon that the economic development of the 19th and the beginning of the 20th century could be represented by model 1, while model 2 is more useful for the period after World War II.[4] However, recent research for the US and for Germany point out that only since 1950 small and medium size firms run by entrepreneurs have brought forth essential and important innovations and discoveries.[5] Therefore both models may be accepted specific in their explanatory power and their importance for the modern theory of technology and innovation will be discussed below.

Although this outline was short and rough it should emphasize SCHUMPETER's aim for a close bilateral connection between economic and technological development. Or, in other terms, here we are speaking of an **evolutionary development** which implies that a market economy develops endogeneously creating innovations, where technological and economic process spur each other - at least by a certain degree.

Based on SCHUMPETER's ideas, several economic disciplines have established special research fields dealing with the relation of technology and economics, e.g. strategic planning, industrial economics, the new business cycle and growth theory, and recently theoretical economic policy. Fundamental to all these fields is a thorough understanding of the process of innovation and its relation to economic reality. Let us therefore turn to the core of our paper, the current state of the economics of innovation.

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4 FREEMAN/CLARK/SOETE (1982), pp.41.

5 DÜRR (1987), FITZROY/KRAFT (1991), AUDRETSCH/ACS (1990).

3. Modern Approaches to the Economics of Innovation

Modern approaches to understand the economics of innovation cover a broad field of questions and problems related to the nature, sources and determinants of technological progress. In this way the neoclassical concept of technology and technological change where the "black-box" argument prevails is challenged. It is the very nature of the contents of this "box" with its economic fundaments and consequences where research is directed on.

One may start here to discuss the process of innovation as a linear process divided into several phases, called invention, innovation, imitation, and diffusion (phase model). However, it turns out that the most interesting questions are on how these phases are connected by forward and backward loops, how economic factors as market structure, productivity, and profitability affect the process of innovation, and how the firm may influence this process actively. Thus, contrary to a linear model the process of innovation may also be discussed as a **collective evolutionary process.**[6]

Another line of research investigates the sources, the pace and the direction of technological progress. We have to mention here the well-known debate on **technology-push**[7] versus **demand-pull** theories[8], each emphasizing one market side as triggering innovations. And additionally one may investigate the relationship between relative factor prices and the direction of technological change as it is done in the literature on **induced technological progress** in the 60s.[9]

However, we cannot follow these aspects and discussions more intensely, this would go far beyond the scope of this paper. We rather want to focus our attention to another interesting problem, the **accumulation of technology** and its economic consequences. To accomplish this task we use a broader concept of modelling the process of innovation. This, however, should not imply that the phase model of innovation or the several economic inducement mechanisms (demand, factor prices) are considered as irrelevant. These aspects or features of technological change are rather to be seen as working within or dominated by the broader concept we shall

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6 This *terminus technicus* goes back to SILVERBERG (1990).

7 See MOWERY/ROSENBERG (1979).

8 Most prominent is here the work by SCHMOOKLER (1966) and by MARQUIS/MYERS(1969).

9 DRANKAKIS/PHELPS (1966), KENNEDY (1964), V. WEIZSÄCKER (1966)

present (and here they remain important and are objects of intensive research). At the end we may show that accumulation of technology leads to differences in technological progress and capabilities which, in turn, affects economic development and "creates" economic structures.

3.1 Conceptional Fundaments of the Process of Innovation

Our first step is entirely taxonomical and we thus want to distinguish innovations

- whether they are to be seen as **radical innovations** followed by tremendous economic changes
- or whether innovations are only **incremental** or **gradual** developing along a well defined technological path.

Now, what are these different kinds of innovations all about?[10]

3.1.1 Radical Innovations and Paradigm Change

By using the phrase **radical innovation** the modern theory of technology and innovation has a change in paradigm in mind. A technological paradigm[11] is defined as the set of special heuristics, scientific principles used, and public as well as firm specific knowledge. In other words, technological paradigms represent a knowledge base with a high potential for development.[12] They define the technological

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10 FREEMAN/PEREZ (1988) distinguish four different kinds of technological progress, i.e. (a) incremental innovations, (b) radical innovations, (c) changes of technology systems, and (d) changes in techno-economic paradigm. However, here for our discussion it is not necessary to go deeper into this matter and discuss the differences between these types. In fact, progress types (b), (c) and (d) vary by and large only by their degree on sectors influenced.

11 The notion of paradigms and change of paradigms was first presented by T.S. KUHN (1962) who used this concept in science philosphy for describing the progress of the sciences. It was DOSI (1982, 1984) who applied this idea to the process of technological change. Other concepts broadly consistent to the notion of "technological paradigm" are "techno-economic paradigm" by FREEMAN/PEREZ (1986, 1988), "focusing devices" by ROSENBERG (1976), and "technological guide-posts" by SAHAL (1981, 1985).

12 DOSI (1988), pp.224-225.

opportunities for further innovation as well as some fundamental procedures on how to exploit them.

Technological paradigms appear to be sector-specific, firm-specific or even country-specific. Of course, nowadays the sectoral aspect is of major importance if we consider the plastics industry, computer technology and prospectively the biotechnology industry as fields with enormous innovative potentials. Many products cannot be produced without using plastics and most offices and industrial productions depend on computer technology.

The abundant (and therefore relatively cheap) availability of a key factor to the production process which furthers and enables the application of this base of knowledge is of further central importance. Such a factor is then to be regarded as the pivotal element of economic development. As fairly evident examples one can presently take oil as a source of energy or semi-conductors as a mode of transmitting information.

A change in paradigm appears as a "jump" of technological opportunities and their further development. Such a change is mainly dependent on scientific progress which by and large is to be rendered as exogenous. This kind of progress is characterized by severe discontinuities which accordingly impose tremendous changes on the economy's structure. We will return to this point later when we discuss "Long Waves" and structural changes.

When is a change in paradigm expected to take place?

An existing technological paradigm prevails and will be improved only as long as it runs into a crisis which cannot be resolved. This means the core elements of the existing paradigm are no longer suitable to solve the actual technological problems. However, it must be mentioned that the crisis within a paradigm does not automatically lead to the creation of a new one. Scientific advances are of major importance for the emergence of a new paradigm. Regardless of the precise mechanism which produces them, new paradigms reshape the pattern of opportunities of technical progress in terms of both, the scope for further development, as well as the ease to accomplish them.

Having discussed the importance of technological paradigms we now want to turn to the discussion of technological advances within such a context.

3.1.2 Incremental Technological Progress

3.1.2.1 Incrementalism and Technological Trajectories

It is fairly evident that not all technological progress is of the radical type characterized by qualitative jumps. We rather may recognize a more or less gradually developing technological level, i.e. product improvements by degrees, increases of production efficiency by degrees, etc. For example, the great success of the Japanese economy in the early 70's is based mainly on the exploitation of small innovation potentials (by reverse engineering or quality improvements) rather than establishing entirely new and revolutionary concepts.

This kind of technological progress is best described as of a more or less improving type. Thus, it is also an innovation if firms develop already existing technology or transfer it to new problems. And hence, these technological improvements are accomplished within a prevailing technological paradigm.

Of course, such technical progress is of a totally different nature compared to a change in paradigm. We say this change is incremental implying a rather continuous process or at least one which is not characterized by severe discontinuities. As yet unknown solutions depend on learning effects which implies that the respective technical progress is dependent on the technological level already achieved. Therefore, contrary to radical progress technological advances develop rather continuously along a so-called **technological trajectory.**[13] And hence, seen abstractly, a technological paradigm is characterized by a **network** or a **cluster** of such trajectories.

As the concept of a technological trajectory is quite abstract, we shall animate it in order to give an idea of its implications for explaining economic development. In the following we will see that it is the technological trajectory which mainly represents the very nature of an **evolutionary development.**

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13 See DOSI (1982). NELSON/WINTER (1982) use the phrase "natural trajectory".

3.1.2.2 The Process of Innovation - A Modified View

First let us state some characteristic stylized facts for such trajectories[14] which altogether describe the process of (incremental) innovation as follows:

(1) The process of innovation is dependent on the present technological paradigm;
(2) it is a cumulative dynamic process;
(3) it is a selective process which
(4) is finalized in a special direction.

All these features provide technological development on a relatively determined path, namely our **technological trajectory.** Let us discuss these features in some more detail.

To get an idea how such technological progress works we have to change the neoclassical concept of technology again. Additionally to sacrificing the "black-box"-doctrine we state: Technology and technological knowledge is not an entirely broadly available good.

Contrary, the neoclassical concept deals with technology as an information which is generally available, always applicable, and easy to reproduce and re-use[15], i.e. technological knowledge is rendered as a **pure public good**. This view has now been modified, and technological innovations are also discussed as having a **private good character.**[16]

Therefore, instead of firms which can produce and use innovations by dipping freely out of a "stock" of technological knowledge, we recognize firms performing totally different from other firms, sacrificing resources for search processes (search costs) and making innovations largely on the basis of in-house technological knowledge. Additionally, it is also evident that knowledge from other firms as well as public knowledge are important sources.

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[14] Dosi (1988), p.225.

[15] See for example Arrow (1962).

[16] For a discussion of the public and private good character of technological know-how see Nelson (1990) and Romer (1990).

What does this modified view of technology and technological development imply for the innovative process?

Private Good Character and Appropriability

As to the private aspect represented by the in-house knowledge base, under such circumstances it is not likely that the search process of firms is one where all technological knowledge available is screened before a technical choice is made. The consideration of **search costs** underline this point since these costs might be the higher the more unfamiliar the field of research to the firm.

Thus, firms on the one hand rather seek to improve and diversify their technology within specific zones which implies technological progress to be **selective** and **finalized** towards a specific direction. And, on the other hand, they try to use their **existing knowledge base** which leads to our feature of technological advances being **cumulative**, i.e. they are constrained by what the firm has been capable of doing in the past and therefore "localized".[17] Consequently, technological change is

(i) to be considered as **path-dependent** where the trajectory, in turn, is dependent on the activities already engaged in, and
(ii) it is to a certain degree **appropriable** by the firm.

This all is not to deny the relevance of other inducement mechanisms as demand or relative factor prices. The firm's reactions on demand shifts or changes in relative factor prices are still important sources for technological change, although they are constrained by the technological opportunities given by a specific trajectory. A major consequence of such a view is that (localized) technical progress leads to new

[17] The *terminus technicus* "localized technological change" is borrowed from ATKINSON/STIGLITZ (1969) and points on the fact that technological progress does not improve all different techniques (represented by different input combinations) given by an isoquant or the production function, i.e. there are no or only minor spillover-improvements (or externalities) in other techniques.

techniques (or new products) which are very likely to be unequivocally superior to the old ones.[18]

To fit it in our picture of paradigm, the technological progress develops within the prevailing technological paradigm. This has a major implication as progress can no longer be rendered as purely stochastic. As the search efforts of scientists, engineers, and technicians do not cover the whole range of possibilities but are restricted to certain fields within the paradigm, progress is constrained and, with time, ceases to be random or dependent solely on market incentives. And in very SCHUMPETERian terms, it is the private good character of technology which makes technological advances at least temporarily appropriable to entrepreneurs and has them earning excess profits. Varying degrees of private appropriability are then both, the outcome of and the incentive to the innovative process.

Public Good Character and Externalities

Let us now turn to the public goods character of technology. All in all, it is clear that technological advances cannot be appropriated entirely. To the extent that firms sell new products or processes, that new principles are reported in journals, that private and public institutions further technological cooperation, etc., one has to consider a non-negligible part of technology as broadly and relatively cheaply available. In other words, technological bottlenecks and opportunities, experiences and skills embodied in organizational forms or in scientists, engineers or technicians may be overflowing from one economic activity to another.

These so-called **technological externalities** are of major importance and describe **non-traded** interdependencies between technologies, sectors and firms. Such effects are, on the one hand, the unintentional outcome of decentralized processes (as industry organization and location, or creation of and adoption to technological standards) and/or on the other hand, the result of the explicit activities of private or public institutions. "Silicon Valley" may serve as an example for unintentional

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[18] Using an isoquant diagramm, for example, factor price changes do not lead to search along the given notional isoquant defined by the existing state-of-the-art as neoclassical theory suggests, but to a jump to another superior isoquant. This implies that with localized technological change the probabilities of going from one low-intensity combination of inputs to another is more likely than going to a high intensity-one. See ATKINSON/STIGLITZ (1969), NELSON/WINTER (1982, pp.175-84).

industry location[19], strategic alliances, the creation of technology parks, and technology and industrial policy (MITI[20], national systems of innovation[21]) as examples for institutional arrangements.

Such interdependencies materialize as technological complementarities, synergy effects, and other stimuli or constraints which are not traded on markets. They can be considered as collective "assets" which belong to firms or sectors within regions or countries, and organize conditions which are (a) country-, region- or even industry-specific; (b) a basic input to the innovation process; and (c) determine and constrain the innovative activities. Hence, we may not only talk of a firm's technological level but also of a certain (common) technological level of a country, region or industry.

3.1.2.3 Development along Trajectories and Positive Feedbacks

Based on our concept of technology we are now able to describe the innovation process along special technological trajectories.

Consider first the development when technological know-how is entirely **appropriated** on the firm level. Here we observe a firm-specific technological trajectory involving the cumulative development and exploitation of internalized, and thus private technological potentials. In all, this view suggests an economic and technological development characterized by firm diversity in the short run and by an (relatively) ordered accumulation of firm-specific technological know-how in the medium and long run.

And also when we take a look at the industry level where at least some of the technological knowledge is **public** and firms produce and improve **commonly** on certain industry standards, we are talking about trajectories specific to industries. Again, on this level economic and technological development is to be seen on the basis of very different sectors and branches which all experience their own

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19 See ARTHUR (1989, 1990).

20 See for example FREEMAN (1988).

21 For a discussion of national systems of innovations see for example LUNDVALL (1988), ANDERSON/LUNDVALL (1988), NELSON (1988), MOWERY/ROSENBERG (1990), CARLSSON/STANKIEWICZ (1991).

accumulation of knowledge and progress of technology - of course determined and constrained by a specific path.[22]

In a third step we can even compare countries (or regions) and evaluate them by their technological level achieved. And again, we find a very heterogeneous picture with industrialized, semi-industrialized, and developing countries. The present discussion about international competitiveness of countries is mainly concerned with this technological aspect. And besides others governments often aim at the international competitive position when they engage in industry or technology policy.

Regardless whether we look at the heterogeneous picture of firms, sectors or countries the leads and lags of the respective economic "agents" or units are mainly determined by the relative technological level achieved, i.e. by the respective technological knowledge **cumulatively** acquired. And here one is likely to observe that a firm, a sector, or even a country which has succeeded in achieving a technological lead will be able to stay ahead for some time.

What is the fundamental reason or mechanism leading to this result?

In order to deal with this question we have to consider phenomena of particular importance for economic development, the so-called **positive feedback-effects** or **dynamic increasing returns**. And here again we have to challenge standard neoclassics although the fundaments of this attack where laid in the very heart of this school.

Neoclassical theory by and large relies on the principle of **negative** feedbacks or diminishing returns to scale. Our understanding of the market is a good example, because when prices for a specific good go up the demand diminishes, which, in turn, precipitates a price drop. Thus, diminishing returns (a) tend to stabilize the economy as changes are offset by just the effects they generate and (b) they imply a unique and predictable solution.

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[22] LEVIN *et al.* (1987, p.1) state in this context: "Market structure and technological performance are endogenously determined by three underlying sets of determinants: the structure of demand, the nature and strength of opportunities for technological advance and the ability of firms to appropriate the returns from private investment in research and development".

With positive feedbacks or increasing returns this does not hold true anymore as changes are **reinforced** by the effects they generate and there is no return to the initial equilibrium. Thus, not one unique equlibrium can be observed but there are several possible outcomes or time-paths an economy can take. Development is therefore more unpredictable and far more complex than in a neoclassical world.[23] And, as we will see, **history** will become important for further development.

How are these positive feedbacks related to our discussion of technology and technological progress? We believe that those parts of the economy which are **knowledge-based** such as the high-tech sectors are also subject to increasing returns. And, of course, for sectors or industries relying more on natural resources we consider the traditional decreasing returns concept appropriate.

Regarding the question of certain stabilitity of inter-firm, inter-sectoral or even international differences in technological levels we can now give a clear-cut answer. When positive-feedbacks are effective technological progress accumulates increasingly, which implies that future success is dependent on the success of the past, i.e. on the technological level already achieved. Or, to put it in other terms, the **cumulative** feature of the innovative process causes so-called **band-waggon-effects** where the technology leader will keep his position for some time and where the followers have to pass through all the stages the leader has already left behind. Thus, we may visualize a competitor's race along a certain path. Responsible for this outcome are above all increasing returns due to "learning-by-doing" and "learning-by-using".[24] With these effects advantages, or disadvantages of course, are reinforced.

Another also important feature of path-dependency is the so-called **irreversibility** or the dependence on history. As we already made clear it is the past that determines the future when we observe the mechanism of positive feedbacks. Therefore, it is also historical chance which determines the relative position of competitors on a trajectory.

Using positive feedbacks as an explanation for the relative technological position is only one aspect. They also have explanatory power in the discussion about how special trajectories are **selected**. Hence, increasing returns are not only important for

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[23] It should be mentioned here that already A. MARSHALL in his Principles (1890) pointed out external economies. However in the main neoclasssical literature this aspect has been almost entirely neglected.

[24] See ROSENBERG (1976, 1982).

the development on a certain trajectory but also for the selection of this trajectory. Let us have a closer look at this phenomenon.

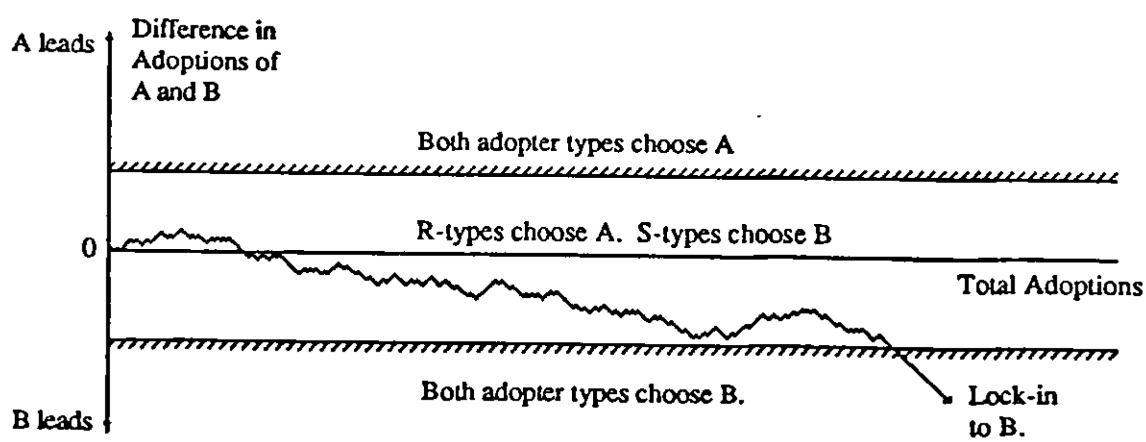
First of all, according to ARTHUR (1990) let us state specific features of positive feedbacks or increasing returns. They are characterized by:

(a) Multiple possible outcomes;[25]
(b) phase locking;
(c) potential inefficiency;
(d) path-dependence.

With this characterization the selective force of increasing returns may be discussed. To illustrate this concept we will use a simple, stylized example which is borrowed from ARTHUR (1989b) and deals with "increasing returns to adoption".

Consider the case of two nascent competing technologies, *A* and *B*, where each one improves as experience with it is gained, i.e. as the number of adoptions increases. This feature is exactly what increasing returns is all about. Let us start out at a position with zero adoptions and where it is totally random what technology will finally win the race. This is shown in figure 3.

Figure 3: Competition between two technologies[26]



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[25] Sometimes the appearance of mulitiple equilibria is called a "determined chaos". STOLPER (1990), CANTNER/HANUSCH (1991).

[26] ARTHUR (1990).

For the process of adoption we have to distinguish two kinds of adopters, ***R*** initially inclined to the *A*-technology, and ***S*** initially preferring technology ***B***. At the early stages the adoption process is entirely random and thus the lead in adoptions - expressed as the difference of adoptions of *A* and ***B*** - is dependent on the identity of the next adopter, ***R*** or ***S***. However, when by chance the share of ***S***-adopters increases rapidly, technology ***B*** becomes sufficiently more adopted and due to our increasing returns more developed. This higher technological standard may in fact solicit ***R***-adopters to switch over to technology ***B***. Finally, both ***R*** and ***S*** adopt ***B*** and only ***B***. Of course, by an other chance the *A*-technology may have succeeded.

What can we learn from this example? We see that it is increasing returns which determine the character of competition between the two technologies. There is more than one possible outcome - the *A* or the ***B*** technology may succeed -, or to put it in economic terms, there are **multiple** equilibria. It is chance, and therefore a small **historical** event, which determines the long-run outcome; the process is therefore **path-dependent.** Increasing returns acting selectively become more and more important as industry grows and with it the market share of ***B***. Here we speak of a **selectional advantage** by technology ***B*** over technology *A*. As this effect is internal to the industry and external to technology ***B*** (or the firm(s) using technology ***B***), there are **external economies** to be observed as described by MARSHALL (1890). Finally, if the one technology is entered at some time, due to high switching costs it will hardly be abandoned again; this means we have to expect so-called **lock-in-effects** on a technological trajectory.

Fairly evident and prominent examples for these kinds of development are the keybord's QWERTY[27], AC-DC-power technique or the video system VHS.[28] Here we stick to special trajectories because to switch to another system would be extremely costly.

What should be pointed out in this context is the fact that special technological trajectories may appear as severe failures after some time which cannot be corrected due to high switching costs. For our examples above we might find better technological solutions, e.g. the video-system "beta-max" is technologically superior compared with VHS. Nevertheless, VHS succeeded (by chance) and a change of the

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27 DAVID (1985).

28 ARTHUR (1990).

system is not very probable.[29] In all, lock-in-effects on trajectories exhibit **potential inefficiencies** which may lead to sub-optimal solutions and which are not, or only with costly efforts, reversible.

We think that this example has shown quite well how increasing returns accruing from externalities may influence technological development. And here again, we find our stylized facts about technology, however not only at the firm level but also applying to an industry, a region or even a country; it is the cumulative and selective feature which may imply selectional advantages and band-waggon-effects, and which appears in the path-dependency and in lock-in effects. And finally, it is again history which determines the final outcome, the one equlibrium selected out of several possible ones.[30]

Summarizing, incremental technological progress develops path-dependent within a technological paradigm where the latter one is considered as an overall concept. Technological and economic progress develops on trajectories or clusters and thus is by no means unbounded as increasing returns become effective. To the extent that technolgical know-how is more private or more public, we may distinguish between trajectories specific to a firm, an industry, and even a country (or region).

Let us now return to SCHUMPETER's models of economic development discussed earlier. How is the relation of these two models to the concept of technology we have just discussed?

Unfortunately, we are not able to draw clear-cut conclusions. However, the idea of a paradigm change seems to be more appropriate to our model 1, designed for the SCHUMPETERian entrepreneur and exogenous technological change. And the

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29 See ARTHUR (1990) and a case study by CUSUMANO *et al.*(1990).

30 There is, however, a discussion on the significance of history *versus* expectations in selecting equilibrium positions (see for example KRUGMAN (1991)). We have to neglect the second aspect here, but we think in our context it is a very important concept.

incremental progress seems to be represented fairly well by our model 2 where technological change is endogenized.[31]

Let us finally make some remarks about what is evolutionary in this concept. To this point there is broad literature comparing evolution in biological terms to that of economical terms[32] discussing all aspects of difference and similarity. However, to understand our concept it is sufficient to mention only three points essential to an evolutionary process:

(1) Within the process of development the conditions, data and parameters of the system are changed continuously. These changes may be incremental (or gradual) or ad-hoc as implied by the terms paradigm change and change along a technological trajectory.

(2) An evolutionary concept renders time not as theoretical and reversible but rather as historical and irreversible. We have stressed this feature by discussing increasing returns and lock-in-effects.

(3) Another core element of an evolutionary concept is the existence of selection[33] processes with its well-known "survival of the fittest". However we have seen that there are several selection processes at work designed to different hierarchical levels.[34] On the firm level the standard competitive selection implying that the firms' survival depends on accomplishing innovations. On the next level survival of firms depends on external factors which by no means causes the fittest to survive. Our discussion of increasing-returns and lock-in-effects has shown these effects. And finally there may be selection processes

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31 What we, rather excursory, want to convey to you as very important in this respect is that neoclassical economists, too, are just on the way to recognize externality effects of technology. It is the "New Growth Theory" suggesting that knowledge spills over from one firm to another and is responsible for increasing returns, which implies that the marginal product of capital needs not to decline. Therefore, an incentive to accumulate capital may persist indefinitely. However, there are yet unresolved questions about these spillovers being exogeneous or endogeneous, or about the carriers of these spillovers, capital inputs or human capital. For these discussions see ROMER (1987), BENHABIB/JOVANOVICH (1991).

32 A good overview to this comparison is given by SCHNABL (1990).

33 In evolutionary biology often the term "sorting" instead of "selection" is used as a broader concept. Selection by struggle of existence is one cause of sorting. See VRBA/GOULD (1986).

34 See GOWDY (1991).

sweeping of entire markets or even economies as we have seen discussing paradigm changes providing new windows of opportunity.

In this context, the modern theory of technology and innovation provides concepts representing one or both of these features. Thus, to speak of an evolutionary view of technological and economic development is in our opinion quite justified although as yet not entirely understood.

3.2 Economic Consequences - Development and Structure

What are the economic consequences of the process of innovation as described above?

Here again, a wide range of interdependent relations between the technological and the economic sphere may be investigated. The effects of different market structures, the relations between productivity and profitability, the issues of sectoral growth and of structural change, and many other topics move into the centre of our interest. We cannot cope with the whole range of questions and therefore we restrict ourselves to the aspects of development and structure.

3.2.1 Development

To start with development, already SCHUMPETER in his "Business Cycles" (1939) points out the relation between economic development and the appearance of innovations. Referring to the Russian economist KONDRATIEFF[35] he discusses the so-called phenomenon of "long waves" or "KONDRATIEFF-cycles".[36] What is the issue here? With respect to technology research efforts by FREEMAN (1977) and MENSCH (1975) provide an answer:

Long waves in economic development are closely related to the clustering of innovations. Above all, the radical innovations, which as we know are combined with a change in paradigm, are of essential importance. Economic history provides several

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35 KONDRATIEFF (1926).

36 It is noteworthy here that research on long waves does not always consider technological changes as responsible for this phenomenon.

evident examples: the railway, electricity, automobiles, plastics, and today of course micro chips. They cause a huge stream of minor innovations which we label incremental and together both initiate a long, durable and self-feeding economic upswing.

It is now the idea that all of these radical innovations cause their respective KONDRATIEFF-cycle. In table 1 we present A schedule stating the five past long waves which has been set up by FREEMAN and PEREZ (1988) and provides information about the length of a wave, its fundamental key input factor, directly and indirectly affected sectors, and finally about international technological leadership in the respective cycle. All cycles are determined by a specific technological paradigm with tremendous influence on economic development. In their beginning they initiate an economic upswing and a paradigm's crisis causes a downswing of economic development.

It is important to recognize that the long up- and downswings are superimposed by cycles of shorter length identified commonly as business cycles. We will not go into this matter any deeper.

The question whether a change of paradigm causes an economic downswing or whether it is just the other way round is yet unresolved.[37] Nevertheless, what is agreed is the fact that a paradigm change leads to far-reaching economic changes. However, its function is only a catalytic one. The actual promotor of growth and development are the incremental innovations developed within the respective paradigm.

Let us just discuss the five waves in more detail. The **first cycle** is connected with the efforts to mechanize production. This triggers a period we all well know as the "Industrial Revolution".
The use of steam power in the Victorian Period initiated the **second cycle** where not only industrial production was rationalized and organized more efficiently, but also transportation was re-orientated.
The **third KONDRATIEFF-cycle** evolved under the banner of electricity. Not before long, products of the emerging electrical industry were to be found more and more in all households and industrial branches.

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[37] See the dispute of FREEMAN *et al.* and MENSCH in FREEMAN (1982), especially pp.3-16; additionally CHESNAI (1982), pp.43-51.

Table 1:

Cycle	approx. Period	Description	Key factor	Main Branches carrying Development	Other rapidly growing Industries	Intern. Technology leaders
1	1770-1840	Early Mechanisation	Cotton Pig Iron	Textils Water power	Steam engines	GB F B
2	1830-1890	Steam power Railway	Coal Transport	Machines Railway Steamships	Steal Electricity	GB F B D/USA
3	1880-1940	Electricity Heavy engineering	Steal	Electrical industry Steal industry Heavy engineering	Automobiles Aircraft Telecommunication	D USA GB F
4	1930-1990(?)	Mass production (Fordism)	Energy (Oil)	Automobiles Petrochemicals Highways	Computers Nuclear power Pharmacie	USA D EEC JP
5	1980-?	Information and Communication-Technology	Chips (Microelectronic)	Computertechnology Software Ceramik industry Service industry	Biotechnology Space activities	JP USA D S

The era of mass production launched by FORD and TAYLOR with the well known "Ford-assembly line" dominated the **fourth wave**. Especially the automobile and the chemical industry took the technological lead here and induced a broad economic upswing.
And finally, since the beginning of the 80's a **fifth cycle** seems to have taken over "control". Computer technology enables the industrial sectors to switch from mass production to specialized and flexible production techniques.[38] And with this new technology also the increasing informational needs of the economy and society will be satisfied better and more comprehensively .

Each respective paradigm also has a specific **main input factor** abundant in supply and therefore relatively cheap. Therefore, this so-called **key factor** is well suited to convey the new technology to all sectors and branches of the economy. In this respect the following is interesting: The specific key factors exit already before a paradigm changes or a long wave begins. However, *a priori* its technological and economic potential is entirely unknown. Only later in the cycle this potential is recognized and utilized. Table 1 shows this for the factors silk/pig iron, for coal/steel/oil, and, of course, for the micro chip. The latter certainly has not been totally exhausted yet, so that quite a number of further incremental innovations may be expected in the future.

Let us briefly summarize:

The theory of long waves suggests that technological paradigms catalyze economic upswings while subsequent incremental innovations sustain it. The whole world economy is affected by this long economic upswing, however, differing from one country, sector, or firm to the other. Thus, we have to recognize the change in existing structures. This will be our next topic.

3.2.2 Structural Change

Economic development on the macro level represented by long waves does not influence all sectors and branches of an economy equally. The impact is specific rather than broadly distributed. There are only certain sectors and firms able of taking a technological lead, and thus achieve high growth rates. In our table each cycle is

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38 Evidence from the chemical industry is reported on in FREEMAN (1990).

characterized by a so-called **core industry** forging ahead of other industries, e.g. the textile industry, machinery, electrical industry, automobiles, and recently the information and communication sector. Of course, after a certain period of time lagging industries will be affected by these dynamic forces too. For this to take place the **diffusion** of innovations into the various sectors is of vital importance. In the current KONDRATIEFF-cycle of computer technology the booming service sector is a fairly good example for being induced by other industries.[39]

A consequence of the unequal distribution of technological and economic chances within an economy is economic structure. Already SCHUMPETER points to this aspect by distinguishing at least an entrepreneur engaged in innovative activities, and a so-called static host.[40] The latter restricts his efforts to the normal economic life and is therefore best characterized as being conservative and administrative. We can, of course, enhance this dual structure[41] and suggest the following:

Technological opportunities on the one hand lead to new economic structures and thus to structural change. On the other hand, technological improvements depend on the technological level a firm, a sector, or a country has already achieved, and on the respective state of an innovation trajectory. Hence, to some extent there exist large differences with respect to behaviour, dynamics, innovativeness, and productivity between firms, sectors, and countries.

Table 1 shows one important result of structural change induced by a paradigm change. With every new paradigm other sectors or branches take the lead in economic development. New core industries advance, push away other sectors and till the ground for followers to be successful. This all leads to considerable structural changes.

Sectoral dynamics are mirrored on the level of firms. Due to firms belonging to prosperous or declining sectors here again we find a very heterogeneous picture of dynamics. Examples are found in our daily newspapers discussing firms' balances and strategies.

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[39] Several papers in FREEMAN/SOETE (1990).

[40] SCHUMPETER (1934).

[41] For a four-sector model see DOSI (1988), PAVITT (1984).

Finally, also countries have to combat in the race of international technological competitiveness.[42] Here, not only the economic but also the political standing depend heavily on success or failure. Table 1 shows that nearly every paradigm change led to a change in the country's ranking. While Great Britain was leading in the era of industrialization and the Victorian Period, with every new paradigm the pool position changed from Germany and the US to Japan. Thus, a change in paradigm gives all nations an (almost) equal new chance in the technology race. **Windows of opportunity**[43] are opened up to all nations. However, during a specific paradigm the international ranking list actually rarely changes.

4. Implications for Economic Policy

To bring our discussion on the interdependence of technological and economic development to a close, we want to present some implications for economic policy. The failure of Keynesian policy advices was one reason for economists to re-orientate themselves. Here want to present some elements of a SCHUMPETERian or **evolutionary economic policy**.

What is the conceptual basis of this kind of economic policy?

With emphasis on "**innovations**" and "**entrepreneurs**" SCHUMPETER's theory of development is devoted primarily to the **supply side** of the economy. Proper conditions for innovative activities and a stable and predictable atmosphere for entrepreneurs are then the main prerequisites to provide prosperity and economic change. Demand side considerations do not matter in any respect, as SEIDL states:[44] "We should remove the fetters red tape, high marginal tax rates, and controls chaining entrepreneurial initiatives. [...] Let us leave the entrepreneurs to take care of the supply, and the demand will follow up of its own accord, because todays needs are still far from being satisfied." Consequently, government and its economic policy should play a more or less passive and meager role.

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42 ABRAMOVITZ (1988).

43 PEREZ (1989), pp.90-92.

44 SEIDL (1984), p.151.

With respect to **technology**, however, even many supply side orientated Schumpeterians think the public sector is intended to be involved **actively**. They base their opinion on the well-known argument of market failure. Advances in technology can be characterized as public goods with the consequence of sub-optimal market outcomes. Private firms will spend less money on R&D than the social optimum would require. Whether this is really true in reality, must remain unanswered. Nevertheless, public good effects are often arguments for an active technology policy leading to high subsidies for private R&D projects.

But, regarding SCHUMPETER as a purely supply-sider, isn't that a too simplistic interpretation of his intention and insights? How is the topic to be handled if we base our considerations on an **evolutionary approach** with an uncertain and unpredictable future? Should the state then become more actively involved or should it still play only a minor role in politics?

In our view the arguments presented above lose their significance considerably within an evolutionary context since they are based on the normal, orthodox view of economic life. NELSON and WINTER put it as follows:[45] "Orthodox theory cannot adequately provide that analysis and understanding because it is an ahistorical world in which genuine novelties do not arise."

But, if we take into account such genuine novelties, then how must the right concept of economic policy be formulated?

We are here indeed not able to present an elaborated frame for an evolutionary economic policy. What we can do is only to try to grasp some ideas without any claim of introducing fully integrated and theoretically based recommendations. Even until now, technology policy lacks a fundamental theoretical framework.

To give an idea of evolutionary economic policy let us start with the effects accruing from an evolutionary development. If this development is driven by the process of **creative destruction**, public policy has to perform at least one major task, as STOLPER[46] has already pointed out. The process of **adaption** following **creative destruction** has to be accelerated. This means, on the one hand, that the prospering

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[45] NELSON/WINTER (1982).

[46] STOLPER (1984), p.7.

sectors of an economy are not to be hindered in their development, and that, on the other hand, declining sectors are not to be kept alive artificially.

A first claim, therefore, could be that government has to secure **income** but not necessarily secure jobs. This could even mean that it should be obliged to speed up the fall of waning sectors.

Consequently this poses some importance on **social policy**. Without a capable system of social security the process of development would be deprived of parts of its impetus. Only social policy accompanying the **creative destruction** will help to make the whole process politically acceptable.

Besides looking at the effects of an evolutionary development economic policy should also deal with the **direction(s)** this development may take. As we have seen there is no guarantee that always the best technology (considered in the long-run) will succeed (survive). However, only a government with full information and perfect foresight can attempt to push the economy in favour of this technology. Of course, this is far from reality. More often it is not clear in advance which technologies have the most potential promise and should therefore be subsidized by governments. Under such circumstances it might be desirable to keep more than one promising technology alive, at least to avoid monopoly problems or to retain certain variety to hedge against future revelations.

Finally we want to emphasize the question of **ecology**. Especially here politics have to recognize that innovations and structural changes to an essential part form the natural environment of mankind. They do not only influence the living conditions of present but also that of future generations. Hence, development cannot be seen and evaluated regardless of these ecological aims in society.

Presently, "end-of-pipe"-technologies seem to be favoured although ex-post they are only able to repair ecologic damage to a certain degree. Knowledge about the process of development on selective and cumulative paths, however, should help to find suitable ex-ante measures. Lock-in effects may also appear optimal to the ecology.

Therefore, another claim might be that government has to care for and install preventive measures which could help ex-ante to protect society from undesirable or even desasterous outcomes. Of course, the future is uncertain, and it is extremely difficult to implement the right means, but doing nothing at all, is undoubtedly the worst of all options.

These examples show how difficult it is to practice economic policy in an evolutionary context. It must be laid out in an indirect way, it has to be complementary as well as acceptable in social and preventive in ecological terms. But even then an uncertain and unpredictable future might disturb all the hopes and aspirations public policy stands for.

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