INSTITUT FÜR VOLKSWIRTSCHAFTSLEHRE

der

UNIVERSITÄT AUGSBURG

New Developments in the Theory of Innovation and Technological Change - Consequences for Technology Policies

by

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Beitrag Nr. 80

Oktober 1992

Volkswirtschaftliche Diskussionsreihe

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Neuere Ansätze der Innovationstheorie und der Theorie des technischen Wandels - Konsequenzen für eine Industrie- und Technologiepolitik*

1. Introduction

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 life without technology is completely impossible. Before the turn of the century economic growth was mainly spured 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*).

The first who pointed out the very significance of technology and technological progress for the growth of economies was Joseph A. SCHUMPETER. Already in 1912 he published his "Theorie der Wirtschaftlichen Entwicklung" where he recognized that the guiding principle of economic development is the creation of something new. What he calls "new" is innovation which is created and introduced to the market by the entrepreneur. In 1942 SCHUMPETER then provided a slightly modified view of a technology driven economic development. There he pointed at the organized and institutionalized search activities accomplished by R&D laboratories of large firms. And based on this perception he developed the idea of economic development as an evolutionary concept.

Since these important contributions by SCHUMPETER the economic discipline has devoted much effort to investigate the nature and determinants of technological know-how and progress. And without any doubt the "Theory of New Technology and Innovation" has become one of the most important research fields in economics.

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* Paper presented at the workshop "Kann die Technologiepolitik von der Innovationsökonomie lernen? Theoretische Ansätze, empirische Evidenz, offene Forschungsfragen", Wissenschaftszentrum Bonn, 17.-18.09.92

will costlessly imitate and use the new knowledge at once (non-rivalness) and expropriate the innovator from his rents. Consequently, up to this point there is no incentive in the market to engage in innovative activities and to invest in R&D.

To give incentives for innovative activities the institution of **patent laws**[5] has to be installed, since the innovator will then be able to appropriate temporary monopoly rents. In a market economy patenting is principally supposed to fulfill the same allocative function as property rights of material factors. Consequently, patenting as an instrument to further indirectly innovative activity is said to be in conformity with the functioning of the market system.[6] Of course, this statement could be discussed and there are a number of objections which state that patenting does not work in just that manner. However, we do not want to discuss these aspects in more detail here.[7]

Market conformity is one problem related to the patent system, another one is its ability to serve as a means of technology policy: Is patenting at all well-suited to further or initiate innovative activities? In this respect it is important to recognize that patenting is by no means able to have innovators or entrepreneurs to appropriate all the rewards of their R&D efforts. This result is primarily based on the fact that patenting has functional and time restrictions.[8] Consequently, to a certain extent, positive technological externalities still arise - despite patent laws. That again has lead to the notion of technological knowledge as a partially excludable non-rival input as ROMER (1990a,b) puts it.

The very fact of such technological externalities accruing from the public good character of technological knowledge now rises the question of whether and how to intervene politically. In this respect one may distinguish two contrary attitudes which, however, both stress the "negative" impact of externalities on the market outcome.

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5 Historically the function patent laws are obliged to fullfill changed. And early on they were not designed as an incentive for innovative activity, but rather as a property right for ideas (natural law) or as a financial claim of the innovator towards the society who gains by the "new" (reward theory). These latter concepts have been discussed intensively and they seem not to be appropriate anymore. Nowadays patenting is mainly justified by the incentive motive.

6 See PROSI (1980, p.641).

7 There are three principal objections: (a) Patenting allows an industry to appropriate rents far too long and too intensely - the "natural" duration until imitation is successful would be sufficient in most cases; (b) patenting biases innovative efforts in directions which more easily economize - results of basic research are protected only by quite a low degree; (c) the exclusion of competitors to use patented techniques leads to substitutive, double R&D efforts.

8 Additionally, (a) patenting is no costless endeavour and (b) the duration of a patent's protection is also determined by innovation races following later on.

A first group of economists is strongly influenced by the findings especially of ARROW (1962), but also by the work of the "New Growth" theorists.[9] There it is shown that in pure market economies R&D efforts are undertaken on a level below the socially optimal one.[10] Consequently, market failures are now a very reason for government intervention in order to increase R&D efforts to the socially optimal level.[11] In this respect primarily R&D subsidies to firms and industries are suggested.

Contrariwise, a second group of economists argues in real neoclassical tradition, and despite the perceived market failures they deny any active government intervention.[12] In their view the patent system only has to be modified in order to improve the appropriability conditions for the innovators. Additionally, with regard to the level of R&D they also argue that it is not the single innovator who has to be considered but all those actors who are engaged in a R&D race. Since only one of the competitors can win, finally the total amount spent on R&D will be even higher than the socially optimal one.[13] Consequently, additional R&D subsidies spent by the government would worsen the situation even more.

To summarize: In the traditional view of technological progress two main directions can be distinguished if one looks at the implications for governmental intervention. One position denies any necessity for policy measures and argues that improved property rights alone would solve the market failure problems. The other accepts the deficiency of the patent system and the resulting market failures and, consequently, suggests governmental subsidies to achieve the socially optimal level of R&D.

3. A Modern View of Technological Know-how and Innovation

Now we know that in a "neoclassical world" the relationship between technological progress and policy measures can be seen in different ways. The analysis behind that

9 See SHAW (1991).

10 In addition to the sub-optimal level of R&D efforts, the indivisibility of R&D projects is often an argument for an active government intervention.

11 This does not imply that the social optimum is also a Pareto optimum because patents allow monopolies to exist (ROMER (1987a,b)).

12 See for example STREIT (1991, p.134), (1992).

13 See for example KITCH (1977). A theoretical analysis is given by DASGUPTA/STIGLITZ (1980) and DASGUPTA/MASKIN (1987).

is primarily based on the public good character of technological knowledge and the degree to which it can be protected by property rights in order to initiate private innovative efforts. However, as already mentioned this approach deals with technology as a merely black-box phenomenon.

Recent research in the "Theory of New Technology and Innovation" has attempted to shed some light into this black-box. The resulting new insights show that technology is a very distinguished subject

(a) which cannot be labeled easily with "public good" alone and
(b) which accordingly has very specific characteristics relevant for economic development and growth.

These insights suggest to discuss and analyse matters of technology rather in a "Schumpeterian world"[14] and not anymore in the traditional framework of neoclassical economics. As a consequence, the attitude towards technology policy and its specific measures has to be changed too as the following discussion will show.

The modern analysis of innovative activities covers a broad field of questions and problems related to the nature, sources and determinants of technological progress. We have to mention here the well-known debate on technology-push[15] versus demand-pull theories[16], each emphasizing one market side as triggering innovations. Additionally, one may investigate the relationship between relative factor prices and the direction of technological change as it is done in the (rather neoclassical) literature on induced technological progress in the 60s.[17] Also of interest is the whole process of innovation with its phases of invention, innovation, imitation and diffusion, its connecting forward and backward loops, and its different economic factors such as market structure, productivity, and profitability which affect the process of innovation. Closely connected hereto is the dicussion of product life-cycles. Last but not least, institutional factors shaping and directing technological progress have been the object of considerable research.

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14 We refer here to SCHUMPETER because he was the first to emphasize a technology-driven economic development.

15 See MOWERY/ROSENBERG (1979).

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

17 DRANKAKIS/HELPS (1966), KENNEDY (1964), V. WEIZSÄCKER (1966).

Although these are quite interesting topics, it is not within the scope of this paper to sketch them all. And, additionally, not all of them seem to be of prior relevance for a discussion of technology policies. Therefore, we rather want to focus our attention to that part of the modern theory of new technology and innovation which is interested in the very nature of technology and its process of development (accumulation of technical knowledge), both seen primarily independent of certain economic facts. In doing so we use a broader concept of modelling the process of innovation. This, however, should not imply that the phase model of innovation (invention, innovation, imitation, diffusion) or the several economic inducement mechanisms (demand, factor prices, market structure) 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 present (and here they remain important and are objects of intensive research).

We therefore intend to present the most interesting results referring to three aspects of technology and technological progress:

(a) the **fundamental nature of technological progress,**
(b) the **accumulation of technological know-how** and
(c) the fact that technological progress may be considered as a **cultural evolutionary process.**[18]

In stressing these features of technology and technological progress we get , at the same time, the necessary prerequisites for a direct comparison of our approach with the black-box, public good view employed by neoclassical economics.

3.1 Technology and Technological Progress - Public versus Private Good

Our first step is to investigate whether the assumption of neoclassical economics holds that technological know-how is a pure or at least - due to patenting - a partially excludable public good. Our first objection hereto is that technology and technological progress is no unitary phenomenon but that it can be unpacked.

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18 This notion is found in NELSON/WINTER (1982).

Our point of departure is the question on how technological knowledge is acquired and to what degree such knowledge is relevant and applicable in an economy. Starting entirely taxonomical we idealize and distinguish between

- broadly applied technological knowledge where innovations are to be seen as radical or generic
- and specific technological knowledge which is improved on by only incremental or gradual innovations.

Now, what are these different concepts all about?[19]

By discussing broadly applicable technological knowledge and radical innovations the modern theory of technology and innovation refers to the concept of **technological paradigms**[20] and **paradigm changes** respectively. A technological paradigm is defined as a set of generic knowledge that provides understanding of how things work. Important in this concept are the key variables affecting performance, the nature of currently binding constraints, and promising approaches to pushing these back.[21] In other words, technological paradigms represent a knowledge base with a high potential for development.[22] They define the technological opportunities for further innovation as well as some fundamental procedures on how to exploit them.

As prominent examples in this respect and as fields with enormous innovative potentials serve the plastics technology, computer technology, and prospectively the biotechnology and the ceramics industry. Many products cannot be produced without using plastics and most offices and industrial productions depend on computer technology. Consequently, the technological knowledge provided by a technological paradigm is characterized by its far reaching impact on many sectors and branches of

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19 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 paradigms. However, for our discussion here 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.

20 The notion of paradigms and change of paradigms was first presented by 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).

21 See NELSON (1990).

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

an economy. Sometimes for those technologies the terminus technicus "General Purpose Technologies" is used.

The knowledge and principles associated with such a paradigm can broadly be rendered as being a socalled **latent public good.**[23] Such a good has the capacity to benefit many parties and compared with the cost of invention or discovery it is inexpensive (if not costless) to learn how to get it used. It is now tempting to think of generic knowledge as representing "sciences"[24] and new generic knowledge as symbolizing scientific advances. This might be true to some degree, but a quite considerable portion of generic knowledge is also the generalized result from operating and design experiences. Despite this qualification, however, the "sciences" are well suited to cope with public good features of (new) knowledge (paradigm change) since there the incentives[25], more or less, are such as to rapidly diffuse new findings and not to appropriate any economic rents.[26] For this reason such (scientific) progress can be, by and large, rendered as outside the economic sphere, i.e. exogenous.[27]

Without any doubts, scientific advances ever had an important influence on the technological development and, as the theory of long waves has shown, also on economic development. However, what one can observe is that not all technological advances are broadly applicable and that not all technological progress is of the radical or generic type. We may recognize a rather **localized**[28] **use of technology** and more or less **gradually improving technological levels**, i.e. product improvements

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23 See NELSON (1990).

24 See NELSON (1990, pp.9-10).

25 For a good description of the incentive system in the "sciences" to disclosure new knowledge see DASGUPTA (1987).

26 However, it is not only the discovery of some new fundamental principles which induces a paradigm change. Of further central importance is 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. 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 semiconductors as a mode of transmitting information.

27 One may ask here 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.

28 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.

by degrees, increases of production efficiency by degrees, etc.[29] This kind of knowledge has contrary to broadly applicable know-how the features of a **private good.** Below we will discuss how the process of accumulation of knowledge brings about this result.

Incremental technological progress can now be seen as developing within a prevailing technological paradigm and therefore it is of a totally different nature compared to a paradigm change. And, equivalent to what we just said above, one might be tempted here to relate this kind of knowledge to the sphere of "applications" or "applied sciences"[30] and to call the respective progress as "improvements in applications". Here again, however, the equivalent qualifications apply as above; there are surely cases where it is known that a technique works although it is not well understood (in sciences).[31]

Nevertheless, according to the localized character of technological knowledge unknown solutions to technical problems depend on **local learning effects**. This implies that the respective technical progress is dependent on the technological level already achieved. Therefore, contrary to radical progress, incremental technological advances develop rather continuously along so-called **technological trajectories**.[32] And hence, seen abstractly, a technological paradigm is characterized by a network or a cluster of such trajectories.

For such a view of incremental technological progress, developing along trajectories, the modern approach suggests that the generated technological know-how has the features of **both public and private goods**. For the technological development - and finally for the economic development - both features have to be seen in their combined effects. However, for analytical purposes it seems appropriate to discuss them separately which allows to focus more intensely on their specific implications.

So, let us turn first to the private good character of incremental technological progress.

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29 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 improved upon by quality improvements) rather than establishing entirely new and revolutionary concepts.

30 DASGUPTA (1987) uses "technology" instead of "applied sciences".

31 See NELSON (1990, pp.9-10).

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

3.2 Accumulation of Technological Knowledge at the Firm Level

The fact that considerable incremental technological progress has the property of a private good has important consequences for the accumulation of technological knowledge at the firm level. In this respect the theory of innovation and new technology has pointed to some characteristic stylized facts for such progress:[33]

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

For the search process of firms it is not likely that all technological knowledge available is screened before a technical choice is made. The consideration of search costs underlines this point since these costs might be the higher the more unfamiliar the field of research to the firm. Therefore, instead of firms which can produce and use innovations by dipping freely out of a "stock" of technological knowledge, we have to recognize firms performing totally different from other firms, sacrificing resources for search processes and making innovations largely on the basis of firm-specific, tacit **in-house technological knowledge.**

This restriction of the search processes to specific zones implies that technological progress is **selective** and **finalized** towards a specific direction. And the reliance of search processes on the existing knowledge base necessarily leads to the feature of **cumulative** technological progress; i.e. such advances are constrained by what the firm has been capable of doing in the past and therefore they are localized.

Moreover this specifity of technological knowledge implies that imitation is neither **costless** nor **instantaneous** so that the innovator is able to appropriate rents (without using the patent system).[34] Thus, the more technological progress depends on in-house technological knowledge the more it is to be rendered as a private good whose (temporary) rents can more easily be appropriated.

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33 See DOSI (1988, p.225).

34 ROSENBERG (1976, 1982) has argued that specific techniques do operate effectively only in a special design environment characterized also by the level of past experience. Such techniques can only be transformed from this estabilishment to another one with considerable costs, even if the original operator or inventor is considerably open and helpful.

This private good character of technological knowledge suggests that incremental technological change is to be considered as **path-dependent** where the trajectory, in turn, is dependent on the activities already engaged in, and that the respective rewards are appropriable by the firm even without the use of patenting.[35]

This path-dependency has now four major consequences:

(1) The firm-specificity of technological knowledge and firm-specific technological advances imply **firm diversity** and a **selection principle**[36] based on technological sophistication.[37]

(2) The cumulative feature of technological progress on a trajectory has considerable consequences for **certain stabilitity of inter-firm technological levels**. The fundamental reasons or mechanisms behind this are internal dynamic increasing returns. When these mechanisms 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", "learning-by-using"[38], or even "learning-by-learning"[39]. With these effects already existing advantages, or disadvantages, of

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

36 For a more detailled discussion of this point see GOWDY (1991).

37 For an industry model with firm diversity see for example SOETE/TURNER (1984).

38 See ROSENBERG (1976, 1982). These learning-by-doing effects are internal to the firm. Contrary ARROW's (1962) learning-by-doing is an external phenomenon as the performance of each firm depends on the cumulative performance of the industry in the past.

39 See STIGLITZ (1987).

course, are reinforced. As a consequence, development "traps" into a specific direction which implies so-called "lock-in"-effects.[40]

(3) The fact that (incremental) technological progress develops along trajectories within a prevailing technological paradigm 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 (which just contrary would imply "not selective" and "not finalized") or dependent only on market incentives. This, however, does not imply that to engage in R&D is no risky endeavour anymore. The trajectory rather determines the general direction of progress. Firm engaging in R&D still face the risk to loose in an R&D race or to fail in applying the right concepts and tools.

(4) Finally, an 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 dynamic increasing returns. Therefore, it is also historical chance which determines the relative position of competitors on a trajectory.

This all suggests to consider technological progress as an **evolutionary phenomenon.**[41] To this point there is a broad literature comparing evolution in biological terms to that of economical terms[42] discussing all aspects of difference and similarity. We cannot go deeper into this discussion, but it may suffice here that the fact of irreversible changes of the conditions, data and parameters within the system, either incrementally or in an ad-hoc manner as implied by the terms paradigm change and change along a technological trajectory, sustains such a view.

Summarizing: By idealizing that technological know-how can be entirely appropriated, we observe a specific technological trajectory involving the cumulative development and exploitation of internalized, and thus private technological

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40 In this respect frequency-dependency effects play an important role too, which act by a mechanism of "increasing returns by adoption" (see ARTHUR (1990), DAVID (1985)). Those effects may be responsible for outcomes or trajectories to be followed which ex-post prove to be suboptimal but where high switching costs prohibit to give up the technology originally choosen (ARTHUR (1990), CUSUMANO *et al.*(1990)).

41 Already Schumpeter was aware of analogies between biological and technological evolution (SCHUMPETER (1942)). And also Marshall suggested to compare economic and biological development.

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

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 when we look at the heterogenous picture of firms the leads and lags are mainly determined by the relative technological level achieved, i.e. by the respective technological knowledge cumulatively acquired. Here, one is likely to observe that a firm which has succeeded in achieving a technological lead will be able to stay ahead for some time.

3.3 Technological Spillovers at the Industry Level

Let us now turn to a second aspect of incremental technological progress. Despite the fact that firms may differ in many respects, it is interesting to observe that most industries and branches can be characterized by a specific technological level and by a certain common path of progress. So, one may ask why and how such a common structure can develop. The key argument has to do with the character of local technological knowledge. As we have just explained, at the firm level this knowledge has - to a high degree - the characteristics of a private good. That means it is appropriable. But, at the industry level it may also cause so-called **technological spillovers**.

Such spillovers arise out of two sources:

(a) The first one is the prevailing paradigm which provides the guiding devices for progress so that any innovation (related to this paradigm) includes general principles and methods which are broadly known and easily transferable.

(b) The second source of spillovers stems from the fact that firm-specific technological knowledge may not entirely be appropriated by a single firm but may diffuse to some degree to other firms in the same industry or even in other industries. This process of diffusion may, to some degree, be an unintended one, but, to a much higher degree, it will be planned, organized, and even forced by single firms.

Although we do not deny the importance of spillover effects provided by a paradigm, for the development of industries the second source seems to be of higher importance.

Spillovers of the second type can be best described as **non-traded interdependencies** between technologies and between firms. They "come into live" unintendedly since firms sell new products, since specific new principles are reported in journals, since private and public institutions further technological cooperation, etc. Thus, 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.

With regard to privately initiated spillover effects, firms do not have the sole objective to appropriate entirely all of the specific and tacit know-how. Since firms differ in their technological approaches it is unlikely that their R&D efforts go exactly in the same direction. As studies by LEVIN/REISS (1988) and by COHEN/LEVINTHAL (1989) have shown R&D efforts by different firms normally show up as complements and not as substitutes. Additionally, due to the uncertainty of R&D engagements not only a common knowledge pool, but also common R&D projects may help to reduce and share the risk inherent to innovative activities. Strategic alliances, R&D cooperations or the voluntary creation and adoption to technological standards may serve as examples here. Consequently, in order to learn from the advances of others, firms are willing to provide others with in-house knowledge - at least to a certain degree. And, more generally, this argument suggests that even when incomplete appropriability within an industry diminishes the incentives for R&D, this is likely to be offset by a stimulus to R&D accruing from the ability to use and improve results gained by others.

Such effects can thus be seen as technological complementarities, synergy effects, and other stimuli or constraints which are not traded on markets. And in a way they can be considered as collective "assets" which belong to sectors within regions or countries, and which organize conditions which (a) are industry-specific, (b) are a basic input to the innovation process, and (c) determine and constrain the innovative activities.

Consequently, we have not only to talk of a firm's technological level, but also of a certain (common) technological level of an industry or sector. And by the degree to which 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**.

3.4 Technological Progress as a Cultural Evolutionary Process

Now, how could this industry oriented picture of technological progress be transfered to the macro-level of an economy? This is not an easy question to be answered, because the results at the macro-level are not determined by a simple process of aggregation, as neoclassical economics would suggest. They rather depend on several, most heterogeneous influences. On the one hand, we have the **inter-industry relations** between different firms and different sectors, on the vertical as well as on the horizontal levels. This view applies especially when one considers certain **key industries** and their relation to other sectors, such as the computer industry today, which are the carrier of major technological progress at the macro-level.

On the other hand, we have public institutions like universities, research institutes or other organizations which provide a bridging function between science, basic knowledge and applied technical solutions at the firm level (public infrastructure). Both sides, together, the private good character of technological know-how as well as the spillover effects at the industry level, and the externalities stemming from basic research and science build up the character of technological progress as a macro-economic phenomenon.

It is this combined effect which gives rise to the notion of a **cultural evolutionary process.**[43] Having in mind all the differences which can be discovered by comparing biological and technological evolution, the following is probably the most important one: Cultural evolutionary processes are characterized by the fact that new findings and new useful ways of doing things do not adhere strictly to their inventor or innovator and to specific, well defined users. At least to a certain extent, they are shared among a larger number of contemporaries, i.e. competing firms of the same industry, branches and sectors within an economy. Thus, the capabilities of all are furthered and advanced by the innovative activities and performances of every single one.

This perception of a collectively pushed and developed technological progress at the macro level is a consequent development of the well-known models labelled

43 See NELSON/WINTER (1982), NELSON (1990). ALLEN (1983) used "collective invention" and SILVERBERG (1990) coined "collective evolutionary process" which both point to the same fact.

"Schumpeter Mark I" and "Schumpeter Mark II". Whereas the former deals with the single individual (entrepreneur) as responsible for innovations, the latter is rather concerned with the role of special R&D laboratories (organized innovations) in large firms. The collective evolutionary view does not deny these sources of innovation, but rather places them in an industry context with certain interfirm and certain producer-user relationships and externalities. And, consequently, the driving force may now be seen in the so-called "group entrepreneurship"[44] arising out of a network or system[45] of actors. We will refer to such systems when we discuss policy issues below.

Also interesting in this respect is the question whether large or small firms are better suitable to succeed in innovative activities. The idea of a "group entrepreneurship" resolves this question suggesting that it has to be a sound mix of large, middle-sized and small firms which form the basis of a successful network.

Such a perception finds empirical support in the case of Japan as IMAI/YAMAZAKI (1992) have shown. They coin this kind of organizational progress a "systemic innovation"[46] which is the core element of a model labelled "Schumpeter Mark-J" - refering to the tradition of previous Schumpeter-models mentioned above.

4. Implications for Technology and Industrial Policy

Our discussion of the features of technological knowledge and its development has now important consequences for the question whether and how to employ policy measures to improve and further the techno-economic development of an economy. First of all, the neoclassical position has to be heavily critized on the basis of this technology concept. And, secondly, this criticism has to be used and developed in order to design a more appropriate frame for policy measures.

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44 See IMAI/YAMAZAKI (1992, p.7).

45 In this respect CARLSSON (1992) and CARLSSON/STANKIEWICZ (1991) use the phrase "technology systems".

46 The label "systemic" is borrowed from GOWDY (1992) who distinguished several selection mechanisms where one takes place on the system or industrial level.

4.1 The Neoclassical Position Revisited

As we have shown, the neoclassical approach is based on the market failure hypothesis where the entirely public goods character of technological know-how and progress, with its resulting externalities, is the major problem. To have the market working well these external effects should never come into existence. Consequently, a patent system has to be installed and has to restrain these effects and guarantee appropriability. However, deficiencies in the patents' protection give rise either to intervene with additional government subsidies to R&D (interventionists) or to improve the patent system (non-interventionists). How are these positions to be seen when the modern view of technology and innovation is applied?

First of all, let us focus on the statement that technological externalities always have to be troublesome for the working of an economy. We do by no means deny that technological progress may conflict with the working of market forces - whenever its public good character is referred to. However, this fact should not be seen as to impair with technological development at all. Two points are important in this respect:

(a) The first refers to the appropriability conditions each single innovator faces;
(b) the second is concerned with the positive effects of externalities as pointed out by the notion of a cultural evolutionary process.

First, let us focus on the issue of appropriability. We do not deny that patents are not always an effective measure for all new technological knowledge to be protected. This applies especially for areas of rapid technological change and rapid obsolescence of ideas where the time-consuming and expensive process of patenting is often quite a troublesome procedure. Moreover, patenting mandates disclosure of ideas which opens up the possibility for competitors to design around the patent. As LEVIN *et al.* (1987)[47] have shown in the case of **process innovations** firms consider **secrecy** as an even better protection against imitation than patenting. For **product innovations**, contrariwise, the protection by patents seem to work comparatively well. Secrecy in this case is not very effective and not feasible at all since it is the "new" which makes product innovations marketable and should attract consumers. However, we have shown that besides the patent system and secrecy it is the very nature of technological progress which provides a very effective protection against imitation - or, in other

47 MANSFIELD *et al.* (1981) have provided comparable results.

words, which gives technological knowledge at least temporarily a private good character. The firm-specifity of technological knowledge and the cumulativeness of its accumulation provides a fairly good protection against imitation and a relatively stable lead time (or seen dynamically first-mover advantages).

This has two important consequences:

(a) Innovating firms do not have to rely solely on the patent system to appropriate the rewards from their innovation. There are additional other measures which help to protect against costless and instantaneous imitation, and firms do very well learn which of them to apply. The problem of the patents' deficiencies and the necessity to improve the patent system are not of that importance some (non-interventionist) neoclassical economists would like to make us believe.

(b) This new view of the appropriability problem would in fact suggest to handle the still arising externalities as a fact of minor importance which can be neglected by and large. But, such an attitude would be equally wrong. Because, as we have shown, not the negative but the **positive effects** technological externalities bring about are those which play a vital and very important role in the technological development of industries (and even economies). It is the network of vertical and horizontal information flows and of knowledge transfers which provides **additional stimuli** for innovative activities. Consequently, technological externalities are for good and not for bad.

Thus, the new view of technology and technological progress modifies the neoclassical analysis insofar as the problem of appropriability is less severe and the externalities are an effect to be considered as positive for technological development. Market imperfections arising from technological externalities do not constitute impediments, but just contrary they are a powerful source for further development. External effects which might impair the individual innovator's incentive structure negatively are (over-)compensated by the positive incentive effects given additionally via a commonly pushed technological progress. Therefore, neoclassical direct subsidies on the micro-level in order to bring up the comparatively low level of firms' R&D activities do not apply here anymore.[48] But, what does this imply for the policy

48 Equivalently the argument of excessive (double) R&D (as put forward by the non interventionsts) loses its basis because firm diversity makes it unlikely that the R&D efforts of different firms go in the exactly same direction.

advices to be given? Is there any reason anymore for technology policy measures to be employed? The answer to this question brings us to the next topic.

4.2 Policy Measures to Further Externalities

The effects of externalities[49] on the technological development of industries (and economies) gives a number of reasons for a technology policy to come into action. Our position here can be clearly stated:

External effects due to technological development should be furthered by the public sector and not restrained.

Of course, such a policy cannot go so far as to abolish all possibilities to appropriate innovation rents. Therefore, the measures, all in all, have to aim at a sound balance between private appropriation and diffusion of technological knowledge. Too much appropriation implies a slow or even abandoned commonly pushed technological progress (cultural evolutionary process). And, just contrary, too much externalities must destroy all private incentives to innovate.

How must policy measures be designed in order to generate technological externalities without impeding private incentives?

There are two points relevant for the formulation of specific policy suggestions:

(a) One can entirely focus on the pre-competitive sphere of the economy and look at policy fields such as science policy.
(b) And, one can try to find and formulate appropriate policy measures which apply to the micro-, the meso- and the macro level of the economy.

However, any such suggestions always have to take into account that technological development is a cultural evolutionary process where all the levels and sectors of a market economy are interconnected.

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49 With "externalities" we refer here also to the intended and unintended spillovers.

For analytical reasons we nevertheless want to show what specific policy measures should or should not be applied to each of the above mentioned areas, why they do not work in isolation and how the different measures have to be synchronized on the macro level to be successful.

4.2.1 Pre-Competitive Policy Measures

Considering policy measures to further externalities one can think first of all of instruments which may be applied in the "pre-competitive sphere" of a market economy. The argument is that such measures will be the more successful the more they do not bias market competition. Since there is no interference with appropriability interests of firms it is the "pre competitive" sphere where such policy measures should especially provoke externalities.

To determine policies here it seems again appropriate to distinguish between the breadth of applicability of technological knowledge and the sources of change. Above we crudely distinguished paradigms and paradigm changes related more to science and to tacit, firm-specific knowledge and trajectories more related to the application of technology in the private business sector.

Considering paradigms and paradigm changes policy interventions in this respect are labelled as science policy[50]. The general objective here is to develop and improve **human capital**. It is the level and quality of the education of the people which, on the one hand, are responsible for how and with what success new knowledge is generated and accumulated. And, on the other hand, for countries with a lower level of technological sophistication, compared to the world technology leaders, international technology transfers (catch-up processes) can only be successful if the people are well educated to use and learn on the new devices.

In order to generate pre-competitive technological externalities in the case of firm-specific, tacit technological knowledge, associated with what we called incremental progress, it is even the more relevant to encourage firms in cooperating in pre-competitive R&D. Policy measures[51] in this respect are always guided by the example

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50 See DASGUPTA (1987, p.9).
51 Such policies are coined as "technopolis policies" (IMAI/YMAZAKI (1992)).

of the famous "Silicon Valley" which, however, has not been the intended result of policy action but the unintentional outcome of positive feedbacks due to location.[52] The "Wissenschaftsstadt Ulm" in Germany, "Sophia Antipolis" in France, "Cambridge Science Park" in the UK, or "Tsukuba Science City" in Japan are prominent examples of science and technology parks which where founded to generate technological externalities. However, the working and even more important the success of such "constructed" institutions are to be questioned. The basic problem envolved here is that for a prosperous techno-economic development the connection to the economic sphere, i.e. the market, has to be tight.

This, however, is the principal problem of policies devoted entirely to the "pre-competitive" sphere. They aim solely on **inventive activities** and having in mind a linear model of the innovation process their fundamental philosophy is that more inventions necessarily lead to more innovations. To transform the invention into an economically relevant result, however, is the crucial point if one aims at economic growth and development. And therefore it is the level of **innovations** which plays a significant role since there the nexus between inventive progress and market conditions is expressed at its best.[53]

4.2.2 Technology Systems and Policy Issues

Consequently, policy measures have to take into account both the inventive level as well as the innovative level where the former refers more to the pre-competitive sphere whereas the latter points to the ability to transform an invention into an economically relevant result. The very unit of such a transformation is obviously the firm. However, any measures applying to specific firms or even to certain technologies

(a) would fail to notice and neglect the importance of vertical and horizontal interdependencies among firms for technological development, and
(b) would disregard that it is diversity and not singularity of actors, competences, ideas and approaches which bring about the finally best technological solutions.

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52 See ARTHUR (1990).

53 IMAI/YAMAZAKI (1992) point to the fact that compared to the US in Japan such "pre-competitive" policies as "technopoly policies" have not proved to be successful. Nevertheless, Japan has shown to be the most successful country in transforming inventions into innovations.

And even to focus entirely on industries would neglect their relations to other branches.

Thus, the level our policy measures should apply to is the networks or technology systems on the macro level including the "sciences". This requirement of a more general view of the innovative process has lead to the discussion of **National Systems of Innovation**[54] which describe the **network** of interactions and interrelations between different actors and sectors of an economy. Generally such systems or networks can be characterized by a clustering of resources and the diffusion of technological know-how. As examples one may think of the pharmaceutical sector, electronics and computers, machinery etc. Here suppliers, users, competitors, industry specific bridging institutions as well as universities and other resaerch institutes are tied together by positive technological externalities.

These systems are well suited to exploit economic development potentials of major technologies more fully since they connect the sphere of technology with the one of the market and of the sciences. They therefore are well able to react on new results of basic research as well as on changing market conditions. They even shape market conditions by themselves.[55] In this context IMAI/YAMAZAKI (1992, p.30) point to **strategic flexibility** as an important feature of technology systems or networks. User-producer interactions based on high competences, the role of bridging institutions, cooperative organizational forms on the industry level as well as research institutions and universities are to be mentioned in this respect.

Well functioning technology networks are based on the premise that none of their parts is hindering the transformation of technological progress into economic growth. If, however, frictions in these mechanisms will arise, policy interventions are necessary and appropriate. But, there is no clear-cut answer what policy measures to apply in such a situation. Because the functioning of the mechanisms, the interfirm and interindustry relations, and also the dependence on scientific knowledge change through time and are also different from one country to another.

This fact underlines again our view that the technology driven development of an economy is to be seen as an **evolutionary process** where the core elements are

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54 See for example NELSON (1988), FREEMAN (1988), LUNDVALL (1988).

55 IMAI/YAMAZAKI (1992) point to the fact that networks are able to create markets.

"novelty" and "change". And looking at the history of economic development of the western industrialized world during the past two hundred years one will discover that this process was especially characterized by **key industries** specific to and dominant in certain periods. These key industries have been the major carrier of technological progress and they have a broad but also specific influence on all the other sectors and branches in an economy. As the theory of **long waves**[56] has shown the appearance of such key industries has provoked a significant upswing in econonomic growth and development.

With the appearance of new dominant technological devices (considered as paradigm changes or radical innovations) old key industries lost their importance and new ones have come to dominate. Such events, however, have always been accompanied with sometimes severe structural changes. This implies that the technology system or network will have to change as well.[57] Some industries and sectors which were influenced by or were of considerable importance for the previous key industry will now have a less close relationship to the new dominant key industry.

For a technology policy based on such a system view of technological change this implies the following:

(1) Not all technology systems can be dealt with identically. There exists a **hierarchy of technology** systems with different influences on each other. Consequently, policy measures have to be adjusted to each of these systems. Whereas in one system the bridging function from invention to innovation has to be emphasized, another system may require an improvement of absorptive capabilities. Of course, the position in the life-cycle of such a system is of great importance too.

(2) Technology policy should try to **identify the key industry(ies)** or dominant technology systems which have the most powerful impact on the different sectors in an economy. To improve the performance of the dependent sectors, but also to gather the specific technological requirements in these sectors, it is very important to create network relationships within and between these various branches of an economy.[58] Government, in this respect, has the substantial task

56 See for example FREEMAN/PEREZ (1988) and the literature cited there.

57 IMAI/YAMAZAKI (1992) demonstrate and discuss how such a change from the key industry "automobiles" to the key industry "electronics" has taken place in Japan.

58 In this respect the problem of industry concentration has to be mentioned. If large firms or conglomerates appropriate only innovation rents and not consumer rents, concentration is no

to provide the market with the necessary information[59] which can be used by firms and industries to build up fruitful ties and technological relations with other economic partners. This task is of special importance for an economy where the firms' structure is characterized by a limited number of large firms and numerous middle-sized and small firms. Because for the latter it is sometimes extraordinarily difficult and expensive to get the needed information.[60] In this context IMAI/YAMAZAKI (1992) use the phrase "interdisciplinary overlapping".

(3) With regard to international competition it is also important to have a strong "science" sector. This is, on the one hand, necessary if competences for absorptive capabilities have to build up and, on the other hand, when scientific progress has to provide a new frame for technological solutions.

Summarizing, the system view of technological progress suggests a technology policy which ought to have in mind the following requirements:

(a) It should focus on creating well-functioning **systems** rather than promoting individual firms, industries or technical solutions;

(b) it should stress on creating **variety** instead of furthering individual projects;

(c) it should install **networking** instead of supporting individual actors, and last not least,

(d) it should build on **competence enhancing** instead on merely promoting the creation of new technology.

The success of such a policy in Japan is descibed by IMAI/YAMAZAKI (1992, p.42): "..., it was the change from direct supports such as subsidies or low cost finance to indirect support of their self-help and independence by providing industrial infrastructure of technological diffusion, education and training and cooperative physical distribution systems."

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problem at all and the state does not have to interfere. However, to determine and distinguish these rents is a difficult, if not impossible, task.

59 In this context one could also think of a private market for such information (technology agencies). However, such a market obviously does not work very well and has therefore not gained great importance yet.

60 In this respect the function of the patent system has to be interpreted quite differently. It is not the protective function alone which is so important for technological development, but also the provision of up-to-date technological know-how.

5. Final Remarks

Technology and industrial policy based on a system approach to technological progress requires politicians which are aware and sensitive to network relations. This implies that they are willing to recognize the importance of the private and the public good character of technological knowledge and its implications for the incentive system of innovative activities. Moreover, the complex mechanisms of networks, and here especially of interindustry relations, have to be learned. And, finally, politicians have to be aware of how externalities "flow" within such systems, how they can be furthered and how dampened. In this concern and with respect to international competitiveness the role of sciences cannot be underestimated as long as the bridging institutions towards the innovative sphere work well.

To acquire such competences is a demanding task for politicians. If the critical voices are right which more or less deny that politicians have better competences, with respect to traditional direct R&D subsidies, and that they know better than the private business sector what technology will be successful, this task seems even more demanding. On the other hand, competences required to set **incentives for a selfworking evolutionary process of technological development** seem not to be as specific and as doubtful as the ones required by subsidizing individual firms or technologies. In any case, the Japanese example shows how the public and the private sphere can work together in a very fruitful manner, of both sides know the **secret of technological** (and economic) success: It is the notion of "external economies" which stands behind that story of unbelievable accomplishment; and, it is the acceptance of technological development as a cultural evolutionary process.

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