TECHNOLOGY POLICY IN *THE PROCESS OF CHANGE:* CHANGING PARADIGMS IN RESEARCH AND TECHNOLOGY POLICY?

Gerd Schienstock

Cuadernos de Sección. Ciencias Sociales y Económicas 2. (1995) p. 99-125
ISBN: 84-87471-90-0
Donostia: Eusko Ikaskuntza

Technology Policy is the main practical aspect in CTS studies. Genera//y, states are an important part in the assesment and developing technologies. But traditional values have collapsed, because of serious problems in the implementation, control and distribution of technological development. So that, the actual situation requires new paradigms in orden to rearrange state fuctions in this issue. New practices and institutions have appeared a/ready, which are reflecting a new attitude towards the relationships between technology and state.

La política tecnológica es el principal aspecto práctico de los estudios CTS. Usualmente, los estados son una importante parte de la evaluación y desarrollo tecnológicos. Pero los valores tradicionales han colapsado a causa de graves problemas en la implementación, control y extensión del desarrollo tecnológico. Por ello, la actual situación requiere nuevos paradigmas a fin de reorganizar las funciones del estado en esta materia. Han aparecido ya nuevas prácticas e instituciones que reflejan una nueva actitud hacia las relaciones del estado con la tecnología.

CTS ikerketen alderdi praktiko nagusia politika tekonologikoa da. Estatuak, normalean, ebaluaketa eta garapen teknologikoaren alderdi garrantzitsua izan ohi dira. Balio tradizionalak, ordea kolapsatu egin dira garapen teknologikoaren ezarrera, kontrola eta hedapena direla eta. Horregatik, oraingo egoerak paradigma berriak eskatzen ditu gai honetan estatuak dituen funtzioak berrantolatzearren. Dagoeneko, praktika eta instituzio berriak agertu dira, eta horiek estatuak teknologiarekiko harremanetan duen jarrera berria islatzen dute.

1. INTRODUCTION

There is no modern industrialised country not pursuing research and technology policy[1] in one way or another. Although state interventionism in general is viewed more and more sceptically and despite an increasing shift towards favouring the regulating power of the market, hardly any call has been voiced thus far for the state's withdrawal from the fields of research, innovation and technology. To the contrary: not only is public R & T policy considered to be as indispensable as ever for stimulating economic growth, but it has acquired an even growing importance within the scale of state activities. It may be expected that, as knowledge about the complexity of technological innovation increases, state R & T policy will gradually develop into an independent policy field (see Edquist, this volume).

Rather than asking for an expansion of technology policy along existing lines, critics refer to the lack of attention devoted to the social shaping of technological development, as well as to the social compatibility of technological change. Moreover, it is pointed out that there is a lack of ecological precautions and environmentally - benign technology - a deficit whose solution is also expected from the state. What one has in mind, though, is not an expansion of R & T policy by complementary measures which take into account social and ecological aspects. Rather, there is a generalized call for either an integrative or systemic technology policy. According to OECD, there is a need for complete re-orientation within this policy field. Its substance must be newly defined, new spheres of intervention must be identified and new structural arrangements must be developed (OECD 1988). In the following, some of the tendencies shall be pointed out of such a re-orientation in state R & T policy.

2. TRADITIONAL MOTIVES FOR PUBLIC R & T POLICY

Discussions on the justification of state R & T policy are generally based on the assumption that economic growth is the central indicator of social well-being - and as such, constitutes a high-ranking societal goal. In turn, decisive growth impulses are said to emanate from technological innovation. Disruptions in the course of technological

1. In the following, the abbreviation R & T policy shall be used

development - are typically depicted as a linear phase scheme; while here, for reasons of simplification, the three stages of research, innovation and diffusion shall be distinguished. Because such disruptions constitute a danger to economic growth, there is therefore a major societal interest in overcoming them (see Braun, this volume).

There is a reason for attributing such an important role in the process of technological innovation to the state: the structural problems arising within the various stages are often not solved with equal efficiency by the market. The market process, oriented along the self-interests of private actors as far as the goal of economic growth is concerned, leads to an insufficient level and/or to an inappropriate structure of national economic innovation. The central task of state R & T policy is considered to be to correct or even to avoid any such deficiencies by influencing innovation. Moreover, the latter should basically continue to follow market economic principles (Littmann 1975:45). Thus, in justifying state R & T policy crucial importance is attached to the aspect of market failure in achieving economic growth - regardless of how great this failure is considered to be.

The following enumeration includes the major structural problems of the process of technological innovation: According to the theory of economics these are solved unsatisfactorily, if at all, by market-oriented economies: the availability of sufficient knowledge in the natural sciences, the technical or economic indivisibility of large-scale projects, and the lack of transparency of the market (Ewers/Wein 1989). As a consequence, the state is assigned a central role in coping with these problems.

Originally, the justification of state intervention in the process of technological innovation was primarily based on two central arguments. It is generally acknowledged that, at the enterprise level, research is connected with considerable external effects, Especially in the case of fundamental research in the natural sciences, third parties may use new findings without any market transaction having taken place. As in the case of fundamental research, the market economic principle of elimination fails: there is no incentive for enterprises, according to wide theoretical agreement, to invest more heavily in terms of resources in this field (Arrow 1962). This argument is less valid for applied research: in principle, patent protection - as well as the chance to lead in know-how in the long run - provide sufficient incentives for investment by private industry.

Subsequently, as far as research is concerned, market economic regulation, provides an unsatisfactory allocation of resources for attaining the goal of economic growth. This shortcoming is used to justify the fact that, above all fundamental research is not controlled by the market but rather by the state - i.e. that it is either carried out by state institutions or at least supported by these, with results accessible to all market participants (Ewers 1990: 150).

This is all the more true if technological progress is claimed to be based on the "osmosis model" (Hetzler 1970). This serves as the second argument for state R & T policy. This model implies that the extent of fundamental research substantially influences the opportunities for technological innovation - which, in turn, determines the growth rate of the social product. In the case of an inadequate level of fundamental scientific research, the redistribution of resources towards this stage of technological progress makes it possible to initiate a process of national economic growth.

Although there is no doubt that an increase in scientific knowledge raises a society's innovative potential, its utilisation is by no means automatically guaranteed. This is why, in connection with the support of fundamental research, the concept of "conditions providing policy" is used to distinguish it from R & T policy as such (see Boxsel, this volume). Transforming new scientific findings into technological innovation, is basically a matter of those decisions taken by business on how to utilise them. Actions taken at the enterprise level, however, quite often prove detrimental to national economic growth. Therefore, it seems obvious to put the emphasis of state R & T policy on guaranteeing the transfer of technological knowledge, rather than on encouraging and supporting fundamental research. Such a strategy proves rational, especially for small national economies unable to provide the enormous financial means necessary for carrying out fundamental research. Even in Japan, the transfer of modern technology from the leading industrialised nations was originally promoted by the state primarily to initiate a process of economic recovery. Only recently, after Japan's establishment as a leading industrialised nation, has the promotion of fundamental research gained in importance within state R & T policy (see Kawasaki, this volume).

In the case of large-scale technologies, the transformation of scientific findings is also becoming a problem hardly manageable by the market alone. The massive financial requirements resulting from their technological and/or economic indivisibility, quite often exceed the capacities of private companies. In such fields as transport technology, space technology, nuclear energy and computer technology, the governments of most of the large industrialised nations subsequently feel compelled to extend their engagements in technological innovation to fields of applied research. These fields are closer to the market and thus avoid the risk of innovative activities being curtailed due to the financing problems of private industry. However, the following must be admitted as well: in view of the enormous research and development budgets of multinational corporations, the failure of the market in terms of technological and/or economic indivisibility can be used only to a limited extent to legitimatise state research and technology policy (Ewers 1990:151).

The additional danger of fundamental scientific knowledge being transformed into technological innovation, only exists if there is a lack of information on the probability of success of these innovations. This problem is gaining more and more importance: the profitability of investment in high-tech research and development, is hard to estimate due to the long "running-in" periods involved. Although public subsidies may not reduce the risk of failure, they may well reduce related costs. It is argued that, if companies' research expenditure is reduced by state subsidies, then companies will engage more readily in financial commitments difficult to calculate in advance (see Braun, this volume). Public support in these cases, however, is by no means an uncontentious issue: it implies that public institutions are indeed more capable than industrial enterprises to estimate future market risks and, accordingly, that the companies' risk precautions are not justified in case of an appropriate transparency of the market. Reality has proved otherwise:

public institutions' estimations of financial risks in the development and marketing of new technologies, are quite frequently inadequate. The result of this is the permanent necessity of their adopting a role as permanent donors of subventions.

As discussions have shown, a public R & T policy based on economic targets is rather limited in its scope of legitimatisation. State intervention in the process of technological innovation, however, may not be justified by the failure of the market argument alone. One should also consider the necessity of gaining and maintaining international competitiveness (Rothwell and Zegveld 1980). Competitive enterprises in so-called key technology areas are considered to be inevitable if technological dependencies detrimental to the national economy are to be avoided. Here, the perspective of state support does not only refer to fundamental research but also increasingly to the stage of development at the enterprise level.

Public technology policy in Japan is especially characterised by such an orientation towards key technologies. According to McMillan, "The Japanese have learnt the lessons of the post-industrial and information revolution and turned them to competitive advantage" (1984:64). What is characteristic of Japanese R & T policy, is that the economy is regarded as a bundle of sectors, branches and industries. All of these are analysed by the state with regard to such criteria as prospects for the future, net product or world market potential. Also, an optimal composition of the economy is aimed at by special state R & T policy measures encouraging such promising industries as information and data technology, new material technology, biotechnology, automatic manufacturing systems, etc. (see Kawasaki, this volume). In the meantime, however, a number of other countries have also adopted an R & T policy concentrating on the support of key technologies.

This means that national R & T policies are becoming more and more similar. All states promote the development of the same key technologies, without taking into account national specificities or the characteristics of national innovation systems. At present, a vividly-discussed topic is the fact that the semiconductor development is characterised by considerable structural deficiencies in European countries - which bears the risk of a European technological dependence on the US and Japan. This is why, again and again, the massive subsidisation of European companies has been demanded in the development of silicon semiconductors.

Here again, however, the legitimacy of public research and technology policy seems to be questionable at best. For one thing, the argument of the expediency of international division of labour may be used against it. For another, in view of the growing globalisation tendencies of large corporations and the increasing number of strategic alliances being formed, it has become difficult to ascertain which are those enterprises worthy of support in terms of maintaining national competitiveness. In the case of semiconductor development, cooperation between a German and a US corporation at the expense of a European one, raises doubts about the existence of national or Europe-wide support of key technologies. As shown by Edquist, this dilemma of public technology policy may frequently be encountered in small countries (see Edquist, this volume).

Traditional research and technology policy, as well as its bases of legitimatisation, have been subject to criticism in various respects. First, there is considerable doubt about the basic assumptions of the "osmosis model". It may by no means be clearly proved whether the support of fundamental research over various stages of the innovation process, finally leads to the development of new marketable products and processes - and thus, to economic growth. The substantive growth processes which took place in the highly-developed industrialised countries after World War II, may not even predominantly be attributed to state innovation policies. It certainly seems equally justified to name a variety of other factors as having caused them.

By the same token, there is no definite empirical evidence that international competitiveness may be guaranteed by means of state policy. It is true that public research and development subventions are provided massively in those areas where individual industrialised nations hold a particularly strong position in international competition (Krupp 1987). A clear-cut assignment of cause and effect, though, is hardly possible. Also one may consider the thesis of plausible state research and development policy as being attracted by economic success rather than as causing it. In any case, it is difficult to prove the success of traditional innovation policy with regard to the objective of initia ting economic growth.

However, traditional R & T policy is criticised not only because of the uncertain prospects of success. It is also questioned because of its traditional understanding of technology development and policy. Economic competitiveness is exclusively related to technological progress; thus, a substantive conception of technology prevails (see Braun, this volume). According to this narrow definition, technology is understood in terms of machines and production facilities. Accordingly, public R & T policy concentrates on the support of scientific findings and the development of substantive technology. However, there is much room for doubt as to whether the competitiveness of enterprises on the world market depends exclusively on the modernity of substantive technology. Conversely, it might be the other way around: as shown by the example of Japan, organisation and management aspects play an equally important role. This implies that the traditional, technologically-oriented R & T policy must accept the argument regarding the limits of its purely technological approach towards an optimal path to economic growth. At the same time, the question is raised again, though from another perspective, in how far state interventionism is expected to interfere in market-oriented stages of the technological innovation process.

3. FROM SUBSTANTIVE TECHNOLOGY TO TECHNOLOGICAL PRACTICE

In recent debates on Fordism, it has become clear that the progress in productivity connected with its diffusion was not due to the mere technical innovation of the conveyor belt: rather, this was possible only in combination with an appropriately adapted , work organisation and enterprise culture (Boyer 1988). Mechanisation of production, Taylorist principles of work organisation and a bureaucratic management concept form an entity, so to say; it is their interaction that can be considered the secret behind the marked stage of growth after World War II. Hence, Fordism as a new technological paradigm was not only characterised by technological progress, but also by changes in work organisation and enterprise culture.

This is an expression of a changed basic understanding of technology. The substantive technology concept is replaced by a relational one (Rammert 1989). Technology is defined as an organised system of men and machines in which scientific findings and experience are applied in the solution of practical problems (cf. also Dufourt 1990, quoted in Abdelmaki and Kirat, this volume). In this connection, Pacey talks about technological practices (1983:6) which, apart from a technical dimension also include both an organisational and a cultural dimension. Technological progress is thus a process of combined techno-organisational and socio-cultural innovation.

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

Serving as the basic assumption is, on the one hand the autonomous development of the technological paradigm in the form of hardware; and on the other, the social paradigm in the form of software (Dosi 1982). The utilisation of scientific findings may already have resulted in the development of concrete technologies; however, the systemic combination of these hardware components with relevant software programs, can only be considered to be in an experimental stage. The same is true, for that matter, for the supervisory structure, the regulation of working conditions and certain aspects of organisation culture. In any case, it cannot yet be foreseen which combination of hardware and software components, work organisational norms and enterprise culture patterns may finally be considered as the most promising technology line with respect to productivity and growth development (see Badham and Naschold, this volume).

The susceptibility towards a variation of technological system configurations becomes obvious in the case of the conception of CIM systems. There, at least two technological practices have developed. According to Bridner, there is a technocentric and anthropocentric development line (1985); and according to Badham, a neo- and a post-Fordist one (this volume). The two totally contrary systems - both of which differ in technological structure, machine programming and regulations of work organisation - are above all based on different appreciations of human labour. A similar argument is used by Kern and Schumann, who discover in their analysis of new production concepts a management philosophy totally different from Taylorism. They are influenced by quite specific organisational culture patterns (Kern and Schumann 1984).

The concept of technological practice suggests that the productivity potential of new technologies may be fully exploited only in connection with organisational and socio-cultural innovations. Due to their systemic or paradigmatic character (Brandenburg et al. 1976, Mensch 1977) the implications of new technologies - especially if based on advanced electronics - go beyond the sphere of work at the enterprise level. To allow for their efficient application, changes in a variety of societal institutions have also become necessary. According to this basic idea, new technologies represent a scientific development so powerful that it puts into motion entire whole chains of technological and social innovations (see Braun, this volume). In this connection, Nelson and Winter talk about generalized natural trajectories of technology (1977, 1982).

In her concept of “techno-economic paradigm”, also Perez emphasises the importance of the connection between technological progress and societal change (1987). Successful techno-economic paradigms are the result of on the one hand the interaction between new lines of development; and on the other both selective mechanisms of the economy and the natural and social environment. Before a new technological paradigm can lead to any substantial productivity rise, it is argued, a crisis of structural adaptation must be overcome. One should add that old institutions and cultural patterns as well become obsolete; they correspond to the requirements of the outdated technological system. A mis-match occurs between new technologies and the old social model of production. This mis-match must be overcome by means of institutional change if the new technologies’ productive potential is to be fully exploited. By institutional change, Perez refers not only to work organisation and management aspects but above all to the educational system, industrial labour relations, societal value conceptions, etc. Crucial importance is attached to the reform of the system of vocational education in connection with the change in paradigm due to the introduction of new information technologies. Their efficient use substantially depends on the degree to which employees are in a position to enter into active dialogue with the technological systems (Loikkanen and SeppÑIÑ, this volume).

The example of the automobile lends itself one again to demonstrating the consequences of paradigmatic technological change. Apart from representing a technological, work-organisational and - as can easily be checked with Ford - enterprise-cultural change in paradigm, the development and acceptance of the new transport technology has been similarly and decisively influenced by massive public investment programs, as well as the rise in mass consumption via wage and social policies. To carry this example further, the oil crisis has not only encouraged new engine development but has also led to the social innovation of the “car-free weekend”. Finally, massive technological development initiatives may be expected in connection with legal regulations for the solution of the recycling problem.

According to what has been said so far, social, cultural and institutional aspects of work organisation at the level of both companies and society may be similarly decisive as technological innovation for productivity and economic growth. This seems to be taken into account by shifting emphases within public R & T policy. While the support of fundamental research continues to be uncontested, the limits have been extended within which public activities are considered to be appropriate (OECD 1988). In view of the central importance of technological practices and systemic technology structures for productivity development, it is argued that effective public innovation policy must comprise considerably more functions than the mere financial support of research and development or the pilot application of new technologies. It must be related much more closely to all those factors either hampering or favoring its development or use (BrÑunling 1986:264). Essentially two groups of factors may be discerned here: socio-cultural factors of work organisation at the enterprise level, on the one hand, and institutional factors at the societal level on the other (see Badham and Naschold, this volume).

The direct or indirect subsidisation of technology development may be of less importance for national economic growth than the elimination of barriers to innovation at the enterprise level or the support of factors stimulating innovation. This fact has become uncontested as a basis of legitimatising public innovation policy. Accordingly, there is consensus in principle regarding the state's active role in establishing both infrastructure and social institutions supporting technological change. This is the case, for instance, with such economic measures as guaranteeing a low interest level; eliminatingprotective tariffs; providing efficient traffic, transport or modern communication systems. In the same way, this extends to an economical energy supply, far-reaching technological standardisation or even the extension of research and educational systems. However, the question of in how far the educational system - including continuing education - is to be adapted to the requirements of technological progress, is being discussed quite controversially. Even stronger reservations exist when it comes to state intervention for the purpose of re-organising such social institutions as the system of industrial relations, property rights or social security.

The central importance of social institutions for technological change, leads to the demand not only for extending but also for centralising public research and develop ment policy. As a consequence, there has been a demand for the systematic integration into public policy of all those policy spheres more or less unintentionally influencing technological progress, i.e. transforming implicit into explicit policy (see Edquist, this volume). Independently of the fact that such a policy perspective is accompanied by enormous coordination problems (see Badham as well as Aichholzer et al., this volume), the question also arises of how far any such dominance of technological progress - as compared with other societal objectives - is desirable at all. The concept of national innovation systems (see Dalum, this volume), stressing the very orientation of public R & T policy towards national institutions and cultural patterns, is getting increasingly widespread in the literature. This suggests at the very least that the relation between technological progress and the establishment of social institutions should not be understood as a process of unilateral adaptation - and accordingly, that there is due justification for maintaining the independence of individual public policy fields from R & T policy. This in no way means, however, the discontinuing of considerations for coordinating public policies.

Even more controversial than the state's role in institutional adaptation processes and in providing infrastructure, is its intervention in designing production and work processes at the enterprise level. There is basic agreement, however, that the social shaping of new technological systems is of eminent importance under the very aspect of productivity; and this consensus also extends to the market as an appropriate medium for the implementation of social models of work organisation within a limited range (Naschold 1986:236). From this perspective, there is quite a significant scope of intervention for state technology policy.

Objections against the state's active role in conceiving the social model of new technologies, primarily, relate to the low impact of supporting projects of a model nature as a means for public R & T policy. This refers not only to the structural conservatism of business enterprises (Child et al. 1989) but also to the problematic nature of the transferability of forms of social organisation at the enterprise level - and thus, the model nature of publicly-subsidised projects. Secondly, the specific sensitivity to state intervention in this field, is due to the fact that intervention into enterprises' production and working processes may not be seen under the mere aspect of productivity growth. Inevitably raised are questions of social compatibility and ecological consequences. Taking into account such problems and thus incorporating non-economic goals as determinants of public R & T policy, means nothing more than questioning the traditional growth-oriented policy pattern and suggesting a complete strategic and institutional re-orientation.

4. THE CRISIS OF GROWTH-ORIENTED R & T POLICY

Thus far, the government policy objective of increasing social welfare has quite indiscriminately been equalled with growth and productivity progress. In the discussions in this chapter so far, however, the decisive argument has been that a lasting increase in productivity cannot be achieved by technological innovation alone: changes in enterprises' technological practices and in societal institutions are also necessary. The technological innovations encouraged by state innovation policy, however, do not lead to productivity increases only; their development, as well as their application, involve considerable risks of both a social and an ecological nature. This has given rise to an increasing scepticism towards the traditional objectives of public R & T policy (see Braun, this volume). Social damage may by far outweigh productivity growth - leading, as a result, to a decline in social welfare.

It is important to note that social and ecological risks are the result not only of the very nature of substantive technology as such, but also of its use under specific circumstances As has been shown quite impressively by Perrow, the ecological risks of modern large-scale technology are primarily the result of a lack of mutual adjustment between social organisation and technological structures (1986). In addition, the hazards to human health as a central social risk are in many cases not due to specific mechanical properties, but rather to work organisation structures and excessive performance standards.

Due to a specific selectivity, the capacity of the market to eliminate social and ecological risks is considered to be extremely low. Consequently, there are a number of further examples of market failure which might possibly contribute to considerable shortcomings of production steering (Littmann 197552): external effects of production and consumption, neglect of social and human standards; as well as differences between private and general economic time spans.

The external effects of production and consumption increase dramatically in accordance with economic and technological development. Environmental damage - such as water and air pollution, the destruction of the ozone layer, as well as the gigantic growth in waste quantities - make it clear that many people's quality of life is considerably diminished by technological progress. Impairing the quality of the free goods of water and air as a consequence of industrial production, raises serious doubts about the positive effects of productivity increase and economic growth on the general welfare.

Scarce resources may be misdirected if environmental protection and improvement are left to the market. This becomes easy to explain when considering as the entrepreneurial goal a ratio favorable as possible between private profits and costs as. In line with this goal, the substitution of private costs for societal ones appears to be quite rational - at least from the entrepreneurial point of view, This applies to the emission of toxic gases in the same way as for discharging contaminated waste water into the rivers. As long as the wasteful use of scarce resources does not reduce profits, there is nothing - from the entrepreneurial perspective -that speaks against the exploitation of nature. Such an externalisation of costs may mean technological progress from the single entrepreneur's point of view; while at the level of society at large, such behaviour results in reduced social welfare.

Specific market selectivity becomes also obvious when considering human-oriented aspects in the conception of technological practices. A decrease in operational costs as a consequence of work intensification due to the use of new technologies, is still considered as technological progress in the traditional sense - even if this goes hand in hand with physical and psychological strain. This assessment, though, cannot be shared on the societal level: there are the considerable social costs, for instance, of medical care and human capital lying idle. Again, costs accrued on the enterprise level during the production process are externalised and must be borne by society as a whole.

Insufficient knowledge of the future scarcity of natural resources is said to be the reason for yet another form of market failure. Market prices, it is argued, are steering mechanisms related to the present, indicating only current scarcities of goods rather than signalling future developments. Hence, such a short-term perspective of the market inevitably leads to inappropriate resource allocation and a misdirection of the innovation process from the point of view of social welfare, One argument along this line, refers to the insufficient consideration of the needs of future generations (Ewers 1990:151).

Such failure of the market is demonstrated by the way of dealing with non-renewable natural resources. The fact that their availability is limited, is hardly reflected in market prices as long as the supplied quantities correspond to demand. In this way, the necessary adjustment processes are deferred - which may lead to considerable friction and slow-down in growth at a later stage. Only if processes of adaptation to future conditions are initiated at a very early stage, can the expected social conflicts be even somewhat alleviated (Littmann 197.557).

The market mechanism contributes to environmental damage, the violation of human standards and the neglect of future situations of scarcity. This fact suggests the need for further perspectives on public innovation control. This does not necessarily suggest renouncing the objective of growth, but rather - and at the very least - a re-orientation in the policy of growth.

There is the widespread view that the development and application of the new EDP-based technologies may solve not only economic but also ecological and social problems. These technologies are not only labelled as clean: they are also supposed to lead to the simultaneous optimisation of economic and social objectives. Stimulating technological progress by supporting research in new technologies and possibly in their pioneering application as well - is thus considered as a comprehensive form of state intervention no longer requiring any additional orientation towards ecological and social objectives. Rather, there should be emphasis on maintaing the basic pattern of technology support.

Daneke criticises the idea that such a conception of new technologies makes them a kind of panacea. He argues, however, that these are not unproblematic from the ecological point of view. In addition, they place high demands on enterprise organisation and public infrastructure (see Daneke, this volume) while by no means leading automatically to the creation of socially compatible working structures (see Badham, this volume). If the welfare-enhancing function of technological progress is not to be impaired by any negative effects, ecological and social objectives must explicitly be made the hallmarks of public R & T policy.

5. THE ROLE OF TECHNOLOGY POLICY: SUPPORT OR REGULATION?

At first sight, a simple idea seems to provide a sensible orientation for a type of R & T policy aiming at economic, ecological and social objectives. Littmann describes this basic idea as follows: "Economic-technological innovations which would not be carried out under the conditions of a (distorted) empirical price system, being considered unprofitable from the private enterprise point of view, shall be stimulated provided that they contribute to working towards the socio-economic optimum. On the other hand, those types of innovation must be discriminated against which seem promising of success merely from the financial point of view of private industry but, taking into consideration social costs and profits, would result in no a gain or even in a loss of people's economic welfare (Littmann 197558).

This basic idea seems to suggest a dual R & T policy incorporating both support and regulation. "The two main thrusts of technology policy are the support of technology and the regulation of technology. The former stems mainly from the desire to strengthen the national economy, while the latter is mainly necessary in order to reduce health and environmental hazards caused by the use of technology" (see Braun, this volume). Badham (in this volume) refers to the partial inadequacy of this role assignment of the two instruments. Thus, the development of new technologies - as mentioned above - contains certain aspects of regulation; while, on the other hand, there are considerable difficulties in eliminating health hazards via legal provisions regulating working procedures. It is rather the support of new technologies which might lead to more effective results in this area.

Putting the above-mentioned idea into practice, poses considerable difficulties as well. Above all, the point in time at which the state should intervene by either supporting or hampering the process of innovation, seems to be an open question. Mayntz and Scharpf give a very good illustration of the problematic nature of such a simple recipe as far as fundamental research is concerned. In politics, according to the authors, it is not possible "to nurse the vegetables and pull out the weeds: the same roots feed both the potential for increasing social welfare and for jeopardising it" (1990:61). The knowledge about nuclear fission, genetic engineering, or information storage as such, may not a priori be categorised as supportive or detrimental to social welfare. Thus, the aim of welfare optimisation by public R & T policy may not be achieved by supporting fundamental research only in those selected fields in which new findings are expected to be conducive to welfare, while withholding support in all those areas where new findings conjure up ecological and social risks.

It obviously causes insurmountable problems to attempt to exclude any negative effects of technological progress, be they of an ecological or a social nature, through state control over fundamental research. It does, however, seem realistic to orient this research towards finding solutions to existing problems. It is possible to find out which type of knowledge is necessary for solving a given social or ecological problem. Of course, this by no means guarantees that an adequate remedy to the problem will actually be found. On the one hand, knowing which kind of scientific knowledge is required, does not automatically guarantee success - even if massive financial means are available for the necessary fundamental research. On the other hand, new scientific findings are not immediately transformed into the necessary forms of technology utilisation. In spite of these imponderabilities, it seems appropriate to assign to state policy three main tasks (Mayntz and Scharpf 1990:63):

- generating knowledge to find technological solutions to social problems which have not been caused by technology itself;
- generating knowledge about possible negative side effects of currently-practiced or prospective technological solutions (see also Edquist, this volume); and
- generating knowledge for minimising such side effects and solving problems arising from former technological practices.

What the authors have in mind here, is primarily fundamental research in the field of ecological systemic relationships. However, their policy conception may easily be transferred to social problems. So, for instance, fundamental research may be aimed at finding out where technological practices do not comply with the criterion of social compatibility. Also, research into the adverse long-term effects of work practices can be made the object of fundamental research, in quite the same way as investigating possibilities for confining or totally eliminating such adverse effects. The authors are well aware, however, that the incentive structure currently existing in fundamental research, is hardly adequate for directing scientific interest towards the investigation of ecological cause-and-effect relationships. To the contrary, it is systematically designed to neglect interdisciplinary research. In view of this, it can be seen as the essential task of the state to initiate the kind of institutional change in fundamental research that is necessary for embarking on interdisciplinary problems (Ewers 1990:159f.). In this respect, some of the developments in the Netherlands seem to be interesting. In the course of the 1970s special programmes and courses were established at universities and other research institutes All of this were devoted to investigating the relationships between science, technology and society (see Boxsel, this volume).

There exists a dilemma of not being able to exclude the detrimental effects of technological advances through controlling fundamental research. Its solution is often considered to lie in a specific model of dualistic R & T policy. There have been attempts to reach the goals of stimulating a level of productivity growth conducive to raising social welfare, as well as that of maintaining national competitiveness in the international context by supporting fundamental research. At the same time, knowledge application is controlled by a variety of forms of state regulation, with a view to avoiding undesired social and ecological consequences of technological progress - or at least of limiting possible damage (Braun 1984:123). According to Littmann, it might certainly be much easier to correct any undesired aspects of technological progress on the user level rather than trying to establish an optimally-structured development path for the economy as a whole via the distribution of research funds (Littmann 1975:59). In this connection, Collingridge has drawn attention to the central dilemma of control (1980). This is due to the fact that, during the early stages of development, technological innovation may not be controlled because of insufficient predictability; while later, as social and ecological consequences may appear, it is possible to do so. Control at this stage, however, becomes increasingly difficult, since any changes are extremely costly due to the amount of technological, financial, institutional and cultural investments already made.

State regulation may take the form of either laying down concrete legal provisions or of influencing price setting: for instance, via the levy of taxes or other charges. This is also described by the concepts of normative or economic regulation. Public regulation is discussed above all as a means of achieving ecological objectives..

A great deal of controversy surrounds the issue of which form of regulation is more efficient for implementing non-economic goals in economic life. By means of economic instruments such as taxes and other charges, producers and consumers are supposed to bear those external costs which they themselves have caused and which so far have been paid for by the community (see Simonis, this volume). “Shadow prices” for causing damage to the environment, it is assumed, will make the rationally-acting subjects of economic life use clean technologies and environmentally-benign products so as to avoid the costs arising from legal requirements and price hikes. Logically speaking, state intervention in the price setting mechanism, will lead to the elimination from the market of unclean technologies, to be replaced by environmentally-benign product and process technologies.

As criticised by Abdelmaki and Kirat, this argumentation has some weaknesses (this volume). One major difficulty in fixing “shadow prices” lies with determining the origins of a specific environmental damage - and accordingly, discriminating against the technologies causing the damage. In most cases, it is argued, damage is of complex origins and appears only after some time. Moreover, levies and charges by no means invariably lead to the substitution of production technologies and of products depriving the state and the environment of their clean counterparts. This is primarily a question of how high such “shadow prices” are. The problem is that fixing exact price levels is not possible due to insufficient information on damage caused by a specific technology. They tend to be the result of biased negotiations in which typically rather moderate prices are fixed, mostly providing little incentive for a change in technological practices or buying habits. In addition, the case of future generations is not taken into consideration in this procedure. Of special importance, though, seems to be the argument that trying to fix a price for environmental damage in principle suggests that nature-destructive processes are reversible. However, in most instances, this is not the case. Therefore, ecologically-oriented government regulation by way of price is in principle not suitable for solving the problem of preventing environmental damage (Siderbaum 1990:3).

Legal regulation also has a number of disadvantages. It has proved to inhibit innovation insofar as there is no special incentive for producers to improve the “‘state-of-the-art” beyond maximum permissible emission levels. The latter are generally fixed by the state aiming at the development of cleaner technologies. Those emissions remaining below the standard fixed by the stete, thus do not incur any costs (Ewers 1990:156). Moreover, the problem with setting emission standards is that this must be done at a point in time when the extent of the individual technologies' harmful effects is still largely unknown (see Simonis, this volume). It comes as no surprise that emission standards tend to be too low: as a rule, the expected damage is underrated (Nowotny and Eisikovic 1991). In addition, proof needs to be supplied that the foreseen legal regulations actually lead to the desired ecological effects.

Various authors therefore display a generalized doubt regarding the possibility of efficient state control of knowledge application at the enterprise level, be it via price or legal regulations (Mayntz and Scharpf 1990:65f.). This scepticism may be substantiated by a number of arguments, For instance, it cannot be excluded that - even by far-reaching state control of knowledge application - it is still impossible to prevent the unintended negative side effects of a basically desirable innovation. After all, technological contexts have become increasingly complex and unpredictable. This is also true, for example, with the catalyser, whose use is certainly less harmful to the environment but which poses substantial, formerly neglected problems of ultimate disposal.

In addition, the thesis of controllability of knowledge application is not very plausible because of the fact that new scientific findings by their very nature constitute a public good applicable on a world-wide basis. State regulations, though, do not extend beyond national borders - thus being incapable of preventing certain technological developments as such.

Not even within national borders is it possible to invariably prevent any damage attributable to technological development by state control of knowledge application. As can be seen from the example of nuclear energy, such a policy is powerless as soon as the damage is due to causes lying beyond national borders. This is true in the same way for all those types of emission which cross national borders via air or water pollution. In this case, a technology policy based on regulation can be successful only if supranational bodies check the compliance with technological standards and are also empowered to impose sanctions.

Finally, there are those technologies which are unwanted from the supranational point of view but which are of enormous advantage to individual states. This is especially true for the military sector, In these fields, national technology policy oriented towards controlling knowledge application, cannot achieve any satisfactory results. Even if there is a ban on the military use of nuclear technology in individual countries, this cannot hamper the further development of nuclear weapons.

A series of quite similar problems would pose themselves to a state technology policy attempting to achieve social objectives by means of controlling knowledge application at the enterprise level. Shadow prices for the use of labour in ways detrimental to health, for instance - independently of the difficulty of setting them - would be problematic primarily because of the assumption of health as a renewable good. Legal regulation, on the other hand, is confronted with the problem of proving the causality between damage and specific technologies - an obstacle hardly to be overcome. Chronic diseases are primarily the consequence of complex cause-and-effect relationships in which the coping potential of the person concerned plays a substantial role: in addition, they appear in many cases only towards the end of a person's working life. Even greater difficulties arise if indicators other than health hazards are taken as a yardstick for assessing the criterion of social compatibility: for example, that of self-realisation.

Apart from the various forms of regulation, public contract-placing is considered an especially suitable tool for implementing social and ecological aspects by means of public R & T policy (see Edquist, this volume). By virtue of the mere choice from among several technologies available on the market, the state might conceiveably influence technological development, provided that the level of state demand is of any significance. For instance, vehicles for state institutions might be purchased from the point of view of specifically ecological considerations. Also, private enterprises whose production organisation is considered as exemplary with regard to social criteria, might be given preference when placing public contracts. Admittedly, however, this is only an Indirect way of steering technological progress.

Of much greater significance is the placing of public contracts with the object of providing specific research and development results. There are special advantages to this way of exerting public influence: the expected research and development results may be specified in detail; the instrument of contract-placing may be used in a highly flexible way; and the state, through compiling the contracts, has the possibility of securing itself rather far-reaching rights to controlling the innovation process (Littmann 1975210). However, if this instrument is to be used successfully, there must be a guarantee of interest on the part of private enterprises to take on contracts from the state. What is decisive here, is whether the state monopolises patent rights to research and development results or whether those are also at the disposal of the contracting enterprise.

The chances for putting greater emphasis on social and ecological aspects by means of placing research and development contracts are relatively good within public R & T policy. There are, however, some problems with using this instrument which must not be overlooked. Let us mention here only the difficulty of a technically-adequate specification of research and development contracts by public institutions. As a rule, it cannot be taken for granted that there is sufficient qualified staff with the specific knowledge required for carrying out this task satisfactorily.

Therefore, in specifying contracts and defining the criteria of ecological and social objectives, the state usually has to rely on external know-how. This, however, involves the risk of expertise being provided from the point of view of a later participation in a call for tenders. In order to minimise such a conflict of interests, it seems reasonable to split the process of placing public contracts into several steps. Still, the problem remains that this instrument might be of quite limited efficiency for orienting technological innovation towards ecological and social objectives, due to the insufficient technical qualification of state actors.

6. R & T POLICY AS A SOCIAL EXPERIMENT

In view of the problems pointed out so far, it seems necessary for public R & T policy to adopt new approaches. Undoubtedly of but limited success would be a technocratic policy trying to achieve ecological and social aims by means of interfering in the market mechanism or the improvement of regulatory practices. Such a re-orientation can only be initiated by a change in political decision-making culture and by the development of new political decision-making structures and institutions.

Regarding the change in political decision-making culture primarily with a view to taking into account ecological objectives, a number of demands have been expressed: (Ewers 1990:156f.; Simonis, this volume);

- the obligation of the emitter to prove as non-harmful the effect of emissions;
- the acceptance of heuristic methods of decision-making, since cause-and-effect relationships are insufficiently known;
- the individual obligation to automatically reduce permissible standards; and
- giving priority to less optimistic prognoses.

Quite similar demands can be made on state policy to take into consideration social objectives of technology development. To give only one example, enterprises should be obliged to prove that specific technological practices are not detrimental to health. In addition, abandoning the proof of causality of work-related illness, may be conceived as a basis for political decisions. There is some doubt, however, as to the feasibility of actually implementing such changes in political decision-making culture. This explains an approach which, unlike the call for a change in public decision-making culture, does not aim at an automatic expansion of state control or regulation over the dynamics of technological development. Rather it chooses to aim at a redefinition of the conditions for legitimatising regulatory policies (Nowotny and Eisikovic 1991).

It would certainly be asking too much to assign to the state the role of central societal control - including the definition of basic technological development lines, the establishment and administration of comprehensive research and development programmes, and the control of knowledge application at the level of society. One factor would be the immense coordination problems involved in such a process, In addition, as previously mentioned, it is these very technical qualification barriers that presently speak against such state dominance in the technological innovation process. Thus, a re-orientation of public R & T policy, must in the first place be accompanied by a redefinition of the state's role in the technological innovation process. This should primarily be based on coordination, integration and information. There is more or less unanimous agreement in professional literature that public R & T policy can by no means remain restricted to either supporting technological knowledge or to controlling its application. It seems to be the state's central task to create a consensus on socially-desired and undesired lines of technological development - not least because of the far-reaching social consequences primarily due to the systemic character of new technologies (BrÑunling 1986). At the same time, this means that new decision-making structures should not only aim at integrating external expertise but also at more incorporating democratic elements.

The establishment of technology assessment centres is generally considered an essential institutional innovation aiming at simultaneously pursuing economic, ecological and social ends within the scope of public R & T policy. However, the days seem to be over when one witnessed the heyday of a type of technology assessment oriented towards risk assessment in mere terms of quantity. There are several reasons for this Firstly, risk assessment by various experts - especially in the early stages of the process of technological innovation - have proved to be widely diverging. This makes it clear that risk assessment is highly dependent on the subjective interpretations and interests of experts. In addition, risks of a social or ecological type are often connected with specific technological practices rather than with a specific substantive technology. Here, however, a purely technocratic risk assessment is impossible. Finally, the traditional form of technology assessment - as a rule characterised by centralisation, bureaucratisation and expert-orientation - lacks the democratic element. This is due to the serious social impact of new technology systems, one decisive for an R & T policy based on consensus.

The impossibility of objectivising technological risks involves the danger of specific interests being imposed, even if unintentionally, by way of technology policy. There are various decision-making approaches designed to avoid this problem. Especially in the US, public R & T policy is based on the instrument of concurrent expertise. One has to admit, though, that those views perceived as too critical are often excluded from the opinion-forming process: either they lack the convincing lobby or the necessary resources for scientifically sustaining their ideas. To compensate for this, public R & T policy would have to be committed to increased support for “alternative research institutes”.

The problem of orienting the technological innovation process towards social and environmental concerns, may not be solved by means of expert advice: This type of technology assessment continues to be based on the idea of direct regulatory-interventionist control by the state. However, this means that there is no direct link between technology assessment and the development of new - or the improvement of existing - technologies There is no direct input of knowledge on social and ecological risks into the technological innovation process; only an indirect one exists, via government measures. Moreover, technological practices largely defy the logics of state interventionism. These include, apart form technical, also organisational and cultural aspects. Thus, public R & T policy must watch out for alternatives to the classical centralist technology assessment model based on expert knowledge.

Such new forms of technology assessment have already started to appear on the horizon. At the enterprise level, those directly concerned are increasingly assigned an expert role in the techno-organisational restructuring of production and work processes. Their experience with regard to social and ecological impacts of technology, is thus immediately integrated into the technological innovation process (Naschold 1986; Badham and Naschold, this volume). At the level of society, the institutionalisation of a democratic dialogue between various social groups and institutions constitutes a form of technology assessment (Nowotny and Eisikovic 1991). The idea of “Constructive Technology Assessment”, as spread by NOTA in the Netherlands, is another indication of change in the forms of technology assessment (see Boxsel, this volume).

Characteristic of this change is the transition from public regulation to the self-regulation of technological innovations (Latnik and Simonis, this volume). The state - or rather, the institutions established by the state - confine themselves primarily to the role of providing the necessary conditions for experiments of a socially- and environmentally-oriented technology development and application. Thus, for instance, it may be regarded as the central element of constructive technology assessment, to provide for the networking of researchers, innovators and other social groups according to the idea of a socio-technical - as well as to strengthen the mechanisms of communication and cooperation. Organising such a dialogue pursues the aim of integrating a maximum of social perspectives and interests into the innovation process at a stage as early as possible Accompanying investigations on socially- and ecologically-oriented technological innovations, shall certainly provide additional input into the social dialogue. In this way, this is at least the intention that a continuous learning process will be sat into motion. Moreover, by means of the widest possible diffusion of the knowledge thus gained, there will be a heightening in social awareness of the social and ecological problems of technological progress.

Quite similar aims to the concept of constructive technological assessment are pursued by the SoTech programme of North Rhine-Westphalia (Latnik and Simonis, this volume) as well as by the Integrated Environment programme developed by EPA in the USA (Daneke, this volume). As far as the scope of expansion of such R & T policy is concerned, there is due cause for scepticism. Many state-supported social and ecological experiments are far from having model character, and there is hardly ever a diffusion throughout society at large. Nevertheless, such experiments seem to contribute to a cultural change, in increasing people's awareness of the social and ecological aspects of technology development and utilisation.

7. CONCLUSION

Since its onset, public R & T policy has undergone considerable change. The new understanding of technology may serve as initial evidence of this. While state intervention was originally aimed at material aspects only, now organisational and cultural aspects are increasingly taken into consideration. The object is no longer pure substantive technology but rather technological practices, Moreover, to an ever-increasing extent, social and ecological aspects are integrated into the objectives of public R & T policy, despite its original exclusive orientation towards economic growth. Rather than being predominantly oriented towards fundamental research, the scope of state interventionism increasingly includes those stages of the technological innovation process that are more closely linked to the market. While public R &. T policy was originally part of economic policy, it is gradually developing into an independent policy field closely interlinked with such fields as educational, financial, industrial and labour market policy - to name just a few. Formerly implicit technology policy is thus more and more developing into explicit technology policy, which means that technological aspects are also considered in the form of state influence on these policy fields. Finally, the role of the state in the technological innovation process is also undergoing change. While the state originally understood itself to be the central actor trying to impose specific technological development lines by means of support and regulation, it has recently rather turned into a facilitator and coordinator providing institutional arrangements for the self-regulation of technological innovation. This can also be called a transition from direct to context control. In the following overview, some significant characteristics of traditional and modern technology policy shall once again be compared.

Table 1: Characteristics of traditional and modern technology policy

	Traditional R & T policy	**Modern R & T policy**
Object	Material aspects (substantive technology)	In addition, organisational institutional and cultural aspects (technological practices)
Objective	Economic growth	In addition, social and ecological compatibility
Stage of technological innovation process	Stages of little bearing on the market (primarily fundamental research)	Also stages closer to the market (technology transfer)
Policy integration	Part of economic policy (largely implicit R & T policy)	Independent policy-field closely interlinked with other policy areas (increasingly explicit technology policy)
Role of the state	Central actor of technological - innovation process	Facilitator and co-ordinator of the self-regulation of the innovation process
Instrument	Support, regulation	Provision of infrastructure
Policy type	Direct control	Context control

It goes without saying that this is a presentation of ideal types. In reality, R & T policy in the individual countries is a combination of traditional and modern elements. However, one may clearly observe that such aspects as context control, explicit policy, the combination with other policy fields, integration of social and ecological objectives, greater closeness to the market, and technological practices are all indeed increasingly becoming constituent elements of the R & T policies of individual countries. Nevertheless, the development of a new type of public intervention in the technological innovation process cannot yet be concluded.

REFERENCES

Arrow, K. (1962):
The Economic Implications of Learning by Doing, in: Review of Economic Studies 29, (80/June): 155. 173.

Brodner, P. (1985):
Fabrik 2000 -Alternative Entwicklungspfade in die Zukunft der Fabrik, Berlin: edition Sigma.

Boyer, R. (1989):
New Direction in Management Practices and Work Organization, Paper at the OECD Conference, “Technological Change as a Social Process”, Helsinki.

Brandenburg, A.G., P. Brödner, H.W. Hetzler, G. Schienstock (1975):
Die Innovationsentscheidung. Bestimmungsgründe fur die Bereitschaft zur Investition in neue Technologien, Göttingen: Verlag Otto Schwartz & Co.

Braun, E. (1984) :
Wayward Technology, London: Pinter Publishers.

Braunling, G. (1986):
Ansätze, Konzepte und Instrumente staatlicher Technologiepolitik, in: H.-H. Hartwich (ed.) Politik und die Macht der Technik, Opladen: Westdeutscher-Verlag, 264-277.

Child, J., H.-D. Ganter and A. Kieser (1987) :
Technological Innovation and Organizational Conservatism, in: J. Pennings and A. Buitendam (eds), The Development and Diffusion of Microelectronics, Cambridge, MA: Ballinger Publishing Company.

Coilingride, D. (1980):
The Social Control of Technology, New York: Martin’s Press.

Dosi, G. (1982):
Technological Paradigms and Technological Trajectories, in: Research Policy 11: 147-162

Dufourt, D. (1991):
Les politiques technologiques: une nouvelle rationalité de l’intervention de l’être dans le systéme productif? in: De Brandt J., Foray D. (eds) L’evaluation economique de la recherche et des innovations technologiques. Paris: Edition du CNRS, 351-380.

Ewers, H.J. (1990):
Marktversagen und Politikversagen als Legitimation staatlicher Forschungs- und Technologiepolitik, in: H. Krupp (Hg.), Technologiepolitik angesichts der Umweltkatastrophe, Heidelberg: Physica Verlag, 147-160.

Ewers, H.J., T. Wein (1989):
Gründe und Richtlinien fur eine Deregulierung. Discussion Paper No. 139, Scientific Document from the Technical University, Berlin.

Hetzler, H.W. (1970):
Soziale Strukturen der organisierten Forschung, Dusseldorf: Westdeutscher Verlag.

Kern, H., M. Schumann (1984):
Das Ende der Arbeitsteilung? Rationalisierung in der industriellen Produktion. Munchen: Beck-Verlag.

Krupp, H. (1987):
Forschungspolitik und internationale Wettbewerbsfahigkeit, in: Fraunhofer-Gesellschaft, Jahresbericht 1986, Munchen: 64-66.

Littmann, K. (1975):
Die Chancen staatlicher Innovationslenkung, Göttingen: Otto Schwartz Verlag.

Mayntz, R., F.W. Scharpf (1990):
Chances and Problems in the Political Guidance of Reseearch Systems, in: H. Krupp (Hg.) Technologiepolitik angesichts der Umweltkatastrophe, Heidelberg: Physica-Verlag, 61-83.

Naschold, F. (1986):
Politik und Produktion. Thesen zu Politik und Technologieentwicklung, in: H.-H. Hartwich (ed) Politik und die Macht der Technik, Opladen: Westdeutscher Verlag, 231-241.

McMillan, C. (1984):
The Japanese Industrial System, Berlin, New York: De Gruyter Verlag.

Mensch, G. (1977):
Das technologische Patt. Frankfurt: Fischer-Verlag.

Nelson, R., S. Winter (1977):
An Search of a Useful Theory of Innovation, in: Research Policy 6 (1): 36-75

Nelson, R. S. Winter (1982):
An Evolutionary Theory of Economic Change, Harvard University Press

Nowotny, H., R. Eisikovic (1990) :
Entstehung, Wahrnehmung und Umgang mit Risiken, ed. by Schweizerischer Wissenschaftsrat, Bern.

OECD (1988):
New Technologies in the 1990s: A Socio-economic Strategy, Paris.

Pacey, A. (1986):
The Culture of Technology, Cambridge, MA: MIT Press.

Perez, S. (1987):
Las Nuevas Tecnologías: Una Visión de Conjunto, in: C. Amanarie (ed) La tercera Revolucion Industrial, RIAL, Buenos Aires, Grupo Editor Latinoamericano.

Perrow, C. (1984):
Normal Accidents: Living with High Risk Technologies, New York: Basic Books.

Rammert, W. (1990):
Telefon und Kommunikationskultur. Akzeptanz und Diffusion einer Technik im Vier-Lander-Vergleich, in: Kölner Zeitschrift fur Soziologie und Sozialpsychologie 1:20-40.

Rothwell, R., W. Zegveld (1980):
Innovation and Technology Policy, London: Pinter Publishers

Sbderbaum, P. (1990):
Neoclassical and Institutional Approaches to Environmental Economics, in: Journal of Economic Issues 24 (2): 481-492.