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Ex Ante Evaluation and Technology Assessment - two Emerging Elements of Technology Policy Evaluation

Frieder Meyer-Krahmer
Thomas Reiß

*Fraunhofer-Institute for Systems and Innovation Research (ISI)
Breslauer Straße 48, D - 7500 Karlsruhe, 1, Federal Republic of Germany*

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Abstract

Up to now in many European Countries evaluation of government programmes promoting R&D and innovation is a well accepted procedure of policy assessment. Data and methods used in programme evaluation research are relatively varied and wide-ranging.

Accompanying (or real time) evaluations are the predominant type, often combined with monitoring and ex post analyses; ex ante evaluations are rare. This is a serious deficit, since no systematic basis for decision making is formed, nor are original goals, assumed effects, underlying diagnosis, etc. available as a comparative basis for later analyses.

A second deficit is the inadequate inclusion of technology assessment in programme evaluations. In order to assess the longer term, unintended impacts of public intervention in technology, a stronger involvement of technology assessment is necessary.

This paper describes, in its first part, concepts and methods of programme evaluations, and discusses in its second part strengths and (esp. the above mentioned) weaknesses of evaluation research. Thirdly it presents for the case of evaluation of biotechnology R&D the technometrics approach as a method which contributes to ex ante evaluations. In its final part an example is presented in which way technology assessment can be combined with programme evaluation.

1. Concepts and methods of programme evaluations

The usual definition of evaluation includes the analysis and assessment of (in our context) technology policy goals, instruments and impacts. This definition, however, does not suffice to establish a common understanding, since the shape of R&T policy shows great variations internationally, and also changes substantially over time at a national level, leading in both cases to dissimilar concepts and methods of evaluation.

This can be illustrated by the history of R&T policy in Germany: Up to the mid-1970s, by far the greatest part of public research and technology promotion in the Federal Republic of Germany was concentrated on one stage of the innovation process, R&D. It is only recently that moves have been made in Germany to give more support to subsequent innovation phases such as production start-up and market introduction, or

to the diffusion process of technological innovations, and innovation-oriented services and infrastructure. At this point research and technology policy merges with economic policy. As a result of this history most evaluations have centred on various forms of R&D, but analyses are increasingly extending to other aspects of research and innovation promotion. This development can also be observed in other Western industrial countries, albeit in varying degrees (e.g. BERK/ROSSI 1990, ROESSNER 1989, CHABBAL 1988, GIBBONS, GEORGHIOU 1987, MEYER-KRAHMER, MONTIGNY 1989, BISOGNO, SIRILLI 1989, MEYER-KRAHMER 1989, ROESSNER 1988, OECD 1987).

The concept for evaluation has to match the phases of the development of public technology and innovation policy which can be described as follows. Technology policy is understood here as denoting public influence on technological development and its commercialization. Innovation is taken to mean the process of the development of technologically new or improved products and processes, and their commercialization on the market or adoption in production. The development of a technology policy programme can be analytically divided into three phases: problem diagnosis, programme definition and programme implementation. These three phases are not independent of one another, but are interconnected by numerous operational and strategic feedbacks. Figure 1 gives an overview of these interrelations. Analogously, programme evaluation can be divided into the following categories: strategic ex ante evaluation, which examines the description of problems, the analysis of causes, and possible solutions; operational ex ante evaluation, which analyses the aims and assumptions, the direction and probable extent of impacts of a programme which has already been defined, and contributes to its design; and the evaluation of an implemented or concluded programme (real time, monitoring, ex post evaluation) (see Figure 2). The third type of evaluation is the one most frequently carried out, and is thus easier to describe in detail. It comprises the following elements: Does the programme under investigation represent an adequate solution for the underlying technical, economic or social problem? Are the basic premises of the programme empirically accurate? The first element examines the question whether the programme represents the strategically adequate way of solving the basic problem posed in each case (strategic efficiency). In addition the impacts and effectiveness of public innovation policy have to be examined and evaluated. These include especially the intended and non-intended effects that have actually occurred, analysis of target groups, goal attainment and free-rider effects, as well as the implementation and

running of the programmes. These elements are concerned with the operative and administrative efficiency of the programme under analysis.

The practice of evaluation in Germany has been characterized since the early 1980s by a series of analyses on the use of different instruments in this area. These analyses often concentrate on financial incentives, such as the financial support to specific R&D projects, general subsidies and tax concessions. Measures for the promotion of technology transfer and for the acceleration of the diffusion of new technologies constitute a second main analytical point. These are principally measures in the areas of information, consultancy, procurement of know-how and promotion of cooperation. There are also some analyses on the impacts of public regulation and public demand. (A compilation of evaluations of technology policy programmes in the Federal Republic of Germany is given in Meyer-Krahmer 1991, an overview of evaluations in other European countries can be found in Montigny, Meyer-Krahmer 1989, Bobe 1990). These evaluations use a whole range of different quantitative and qualitative methods, itemized in Figure 3, which are explained and discussed at length elsewhere (Meyer-Krahmer 1989, 1991, Chung, Grupp 1990, Becher 1991, Schmoch, Grupp, Kuntze 1991).

In the field of technology and innovation policies, the major clientele groups that have been addressed are industrial companies engaged in innovative activities (industry support schemes), and public institutions or service companies, offering technical, managerial or financial services to assist innovating industrial companies (infrastructure support schemes). Whereas industry support schemes have been mainly implemented at national level, the promotion of innovation infrastructures and innovation supporting services has been mainly the responsibility of regional authorities. Some of the programmes are experimental schemes (see Bräunling 1991).

The goal of an experimental scheme is to understand the basic mechanisms of a certain part of the innovation system, and to identify possible successful ways of using public intervention. In addition to this, the goals of experimental schemes often include the stimulation and support of institutional learning. Such schemes are limited in time, space and funds. The design of the support structure as well as the specification of the instruments applied may change over time if they are not already based on alternative approaches pursued simultaneously. The role of the state in this context is to act as a catalyst for change and to enable institutional learning processes to take place. Experimental schemes are successful if the actors in this game improve their knowledge

of the possibilities and limitations of their own actions as well as of the main partners in the game, and if the knowledge achieved can be transferred to other fields of action. The role of the evaluator is to facilitate learning processes and to act as an agent for change. He has to be part of the implementation process.

Evaluations of research and technology policy have so far been confined mainly to direct or short term impacts in the area of research and development. There are not many investigations into the medium and long term impacts on the economy and society. The main reasons for this are that the complexity of interactions increases strongly with the length of time elapsing between R&T policy implementation and impact analysis; that impacts are dependent to a high degree on the economic and social context and the cyclic relationships between R&D and innovations as distinct from the simplifying linear model (cf. Grupp 1992); and that there are serious deficits in method and theory (Georghiou 1990).

2. Strengths and weaknesses of evaluations - the case of technology policy programmes in Germany

Since the early 1980s evaluations have been carried out increasingly in Germany (for the following see Meyer-Krahmer 1991). In the beginning they were confined to the examination of general promotion programmes with broad terms of reference addressing small and medium sized firms; in the last few years they have been applied more and more to larger-scale, technology-specific programmes, for instance in the areas of information technology, biotechnology and materials research. These evaluations differ widely in design, breadth and depth of issues analyzed, time horizons, etc. However, it is possible to make some general statements on strengths and weaknesses in the practice of evaluation of technology policy programmes in Germany, bearing in mind that individual instances may deviate considerably (Figure 4).

If one differentiates between type of evaluation, issues, data and methods used, and frame conditions for evaluations, the following picture emerges: accompanying (or real time) evaluations are the predominant type, often combined with monitoring and ex post analyses; ex ante evaluations, particularly strategically-oriented ones, are rare. This is a serious deficit, since no systematic basis for decision making is formed, nor are original goals, assumed effects, underlying diagnosis, etc. available as a comparative basis for later analyses. The aspects analyzed are primarily operative - size and characteristics of the target groups reached, intended effects (mainly on R&D

activities), goal attainment, administrative efficiency. Only in exceptional cases are the non-intended effects and long term impacts of technology policy programmes investigated. This would entail either the completion of analyses with appropriate models - which hardly exist at present - or the conducting of an ex post evaluation several years after termination of the policy programme. Here too there is a deficit, caused mainly by political interest in current technology policy programmes, and by the short term planning horizons of policy administration due to the four to five years electoral cycle. In many evaluations strategic efficiency is also analyzed to the extent of including a critical appraisal of the programme's basic assumptions. However, this area is also in deficit, particularly regarding the analysis of alternative instruments and consideration of the question whether or not the technology policy programme deals adequately with the problem it is intended to address.

Compared to other countries, data and methods used in evaluation research in Germany are relatively varied and wide-ranging. As well as case studies, interviews and surveys, which are used in practically all countries, control group or comparative approaches have been adopted to a limited extent; in particular, various quantitative and qualitative methods which complement and mutually control one another are used together in a "method mix", certainly the most adequate approach at present, since there is no "ideal" method of evaluation. On the other hand, the inclusion of technology assessment in programme evaluations so far has been inadequate (cf. Grupp 1990, Kuhlmann 1992). In order to assess the longer term, unintended impacts of public intervention in technology, a stronger involvement of technology assessment is essential. Although the data basis, especially size and differentiation of samples, is very satisfactory in comparison to other industrial countries, due to the high degree of acceptance of this type of field research in industry and science, most of the data are perceptive, i.e. they mainly reflect the perceptions of those questioned. There is still a deficit in the use of objective data on e.g. the state of technology development before and after programme promotion; this too is a weakness, but one which is not easily corrected (one example, using patent data, can be found in Schmoch, Grupp, Kuntze 1991).

Germany compares well with other countries regarding availability of resources and time taken for evaluations, although from the point of view of timing evaluations have often been begun too late. In addition there is also the insoluble problem that impacts of programmes only begin to show after a time lag, so that the results of evaluations necessarily arrive too late to be incorporated into the policy decision making process. Programmes usually run for a limited time (4-5 years) and decisions on the design of follow-up activities are (or have to be) made about two years before programmes are

discontinued. This problem is sometimes alleviated by interactive forms of organisation in programme evaluation, with numerous feedbacks from evaluators to programme managers. In this situation the evaluation process becomes as important as its results. However, only short term effects can be taken into account; consequently the longer-term results are only available for the programme after the next, by which time they may be obsolete.

One aspect which is very significant for the quality and reliability of evaluations, and which has received a relatively high degree of consideration in Germany so far, is the independent status of the evaluators. Experience up to now shows that this is extremely important, as otherwise the process of evaluation and its results may be too strongly distorted, for example, by the influence of programme managers.

3. Technometrics as a tool for ex ante evaluation - the case of biotechnology

Technometrics has been developed as a method for analyzing the industrial development phase of technological change through the use of output indicators which are derived from technical specifications of products or processes (Grupp, Hohmeyer 1986). Together with bibliometric indicators, patent indicators and econometric indicators technometric indicators are mainly used for monitoring technological change (Grupp, Schwitalla 1989; Reiss 1990; Reiss et al. 1990). In the following it will be shown that the type of information provided by technometric indicators is also valuable for problem diagnosis during strategic ex ante evaluation (compare Figs. 1 and 2).

The basic procedure for *technometrics* utilizing technometric indicators is shown in figure 5. First, the technology which should be analyzed has to be chosen. Second, the countries to be compared, are selected. An essential step for technometrics is the identification of technical specifications which are most important for characterizing the products or processes under review. This identification step is done by taking into account information from scientific literature and, most important, by interviewing experts in the relevant fields. In the next step the most important companies which are active in the technical fields in the different countries have to be identified. Again, expert judgement and, in addition, information about patent applications are used during this step. The most time consuming step during technometric analyses is the collection of values for the technical specifications of the products and processes under review in the different countries. This is done mainly by interviewing experts from the selected companies. The expert information is supplemented by product information.

The calculation of technometric indicators is basically an aggregation and a metric transformation step. During this calculation technological disparities within a national economy are excluded and domestic competition is not considered since all competing domestic companies have access to the same national R&D system. The highest standards among domestic companies are in each case regarded as national standards. During the metric transformation, the technological standard of the country which has made the greatest progress in terms of the specification under review defines the international maximum value $K = 1$. The metric value for the other subsets is determined by the spread of the specifications within each subset and between the different subsets. Finally, the technometric values are compared between the different countries.

An important issue during the strategic ex ante evaluation process is the technological gap question. For the case of biotechnology it will be shown in the following how technometrics can contribute to this aspect.

Biotechnology is a very complex technical field which cannot be analyzed on the whole. Rather it is convenient to divide it into major fields of application (Figure 6). The most important fields are medicine, chemistry, environment, food, agriculture and horticulture, renewable resources and energy. These application-directed subfields are supplemented by methodological orientated fields like the development of new methods, process engineering, enzyme technology, analysis, bioelectronics, and risk assessment.

With respect to the gap discussion, the technometric analysis of biotechnology applied to the solution of environmental problems (Reiss et al. 1990) is particularly illustrative. The technometric comparison of different subfields of environmental biotechnology (Fig. 7) indicates that the ranking of the relative technical performances of different countries depends very much on the particular technical area looked at, even within a certain technical sector of biotechnology. In case of anaerobic treatment of wastewater, there is a clear gap between Japan and respectively Germany as the leading nations and the USA which is lagging behind (Fig. 7). This ranking is reversed in case of the degradation of hazardous waste by biological measures (bioremediation) where the USA are heading the other two nations. For biological nitrate removal technology, no gap could be detected whereas biological phosphorus removal technology is dominated by the USA and Japan with Germany lagging behind.

In conclusion, for analyzing technical performance in biotechnology on an international level it is necessary to differentiate as much as possible in order to detect specific technological gaps. Due to their technique oriented specificity and flexibility technometric indicators are useful tools for such analyses.

The implications of detected technological gaps in general for R&D policy need additional careful analyses which are beyond the scope of this paper. However, for the specific case of biotechnology implications mainly on two levels - deriving technology based environmental standards and future competitiveness - are evident.

Usually environmental standards for e.g. emissions or wastewater effluents on a national level are based on the national technological state of the art. Therefore, in case of a technological gap, these standards will not be as stringent as they could be from a technological point of view resulting in avoidable negative environmental impacts. If on the other hand the national state of technology would be at the leading edge, accordingly the environmental standards would be set close to the technical limit, driving industry to apply superior technology compared to international competitors thereby resulting in a competitive advantage on the domestic market. In long term this advantage would be extended to the international market if the enforcement of higher standards would proceed internationally. Currently, in case of wastewater treatment such an internationalization of higher standards can be observed on EC level.

Biotechnology is widely considered as a key technology which is expected to affect several important sectors of the economy after the turn of the century (OECD 1989). However, it is not clear yet, which of these sectors will be most important. Therefore, from the strategic point of view, it is not advisable to direct R&D activities in biotechnology only into few areas which look promising today. Rather, it is important to extend the knowledge in biotechnology on a broad base in order to respond to future challenges and demands, which may differ from today's expectations. For following such a concept, it is essential first to detect technological gaps and second to device strategic programmes for closing these gaps.

In summary, as illustrated by the case of biotechnology, the role of technometrics in technology policy evaluation (compare Figs. 1 and 2) can be described as follows: Technometrics is particularly useful ex ante for problem analysis, e.g. analysis of technological gaps, and for designing specific topics of public research programmes which may be developed for closing technological gaps. The first case represent the strategic, the second the operational element of ex ante evaluation (Fig. 2). However,

the decision about the necessity of research programmes for remediation of technological gaps cannot be based on technometric or similar analyses alone. Rather, additional information on the impacts and pervasiveness of the technology under review is needed. In the case of biotechnology arguments for developing such programmes have been presented.

With respect to real time monitoring and ex post evaluation (Fig. 2) technometrics is an appropriate tool for the detailed and objective description of the situation before the programme started (see above) and during/after it's running which allows in turn before/after comparisons.

4. Technology assessment as an element of programme evaluation

Technological change as a result of R&D programmes aims at attaining certain goals (see Figure 8). The achievement of these goals can be hindered by not intended impacts from different areas. In order to deal with this problem, technology assessment can be integrated into R&D programmes and be used for fine tuning of programmes to optimize target achievement. An example for such type of technology assessment within a specific R&D programme will be discussed briefly.

Recently in Germany a new programme has been implemented which aims at the investigation of biological methods for producing hydrogen as a source of energy (see BMFT 1990). Since this technology is at a very early stage, a lot of basic research has to be done before applications will become obvious. The important point in this context is that even at this very early stage of technological change technology assessment can be useful because it helps to tune and potentially redirect the whole R&D process. Thereby economic losses due to ill perceived problems which might occur during later stages of technological change can be minimized. The basic scheme of this technology assessment is shown in figure 9. In a first step the scientific and technological development of biological hydrogen production and also of potential competing technologies like photovoltaics have to be monitored. This is done in close cooperation with the participants and managers of the programme. Methods applied for monitoring include S&T indicators as described in the preceeding chapter. In the next step assumptions and boundary conditions for technology development are combined to scenarios which are the basis for the different paths of technology development. For

each of these different paths benefits are estimated and compared with direct and indirect risks. This is the basis for assessment of technology development. The results of this assessment are used to give hints for fine tuning of the programme in order to minimize potential risks.

As an example for the function of this technology assessment within the programme, the approach for risk evaluation of the organisms considered is presented. A central part of the programme is the use of microorganisms for energy production. These organisms finally may be optimized through genetic engineering. Since large-scale applications are a final goal, the potential release of these engineered organisms is a central question for risk assessment. For risk evaluation different categories of risks like e.g. attributes of genetic alteration, attributes of wild type organisms, attributes of the environment with different criteria like e.g. genetic stability, function, pest status have been developed (Tidje et al. 1989). For each of these criteria less or more consideration is necessary. Using this approach, a risk profile for a certain technical option, which is subject of a specific research project within the programme, can be developed. By comparing different options according to such profiles, information on those options with lowest risks can be deduced and used for a fine tuning or even redirecting of the programme.

Thus, with respect to programme evaluation (see Fig. 1), technology assessment represents a new approach for analyzing the operative aspect during real time monitoring.

Programme Development

Figure 1

Figure 2

Programme Evaluation

Figure 3

Figure 4

Strengths and weaknesses of the evaluation practice of technology policy programmes in Germany

Evaluations of technology policy programmes	Strengths (+) and weaknesses (-)
type	
strategic ex ante	very seldom
operational ex ante	seldom
real time/monitoring/ex post	frequent
issues	
underlying assumptions	+
clientele	+
intended effects	+
unintended effects	-
long term effects	-
goal attainment	+
alternative instruments	-
administrative efficiency	+
data and methods	
before/after	+
control group	0
case studies/interviews	+
technology assessment	-
method mix	+
perceptive data	+
objective data	-
size of data basis	+
frame conditions	
resources, time	+
timing	0
independency	+

Source: Meyer-Krahmer 1991

Figure 5

Figure 6

Biotechnology: major fields of application

class	subclass
medicine	drugs diagnostics vaccines
chemistry	fine chemicals bulk chemicals leaching
environment	analysis/control treatment
agriculture and horticulture	plant production animal production
renewable resources	
food	process technology starter cultures enzymes additives analysis/control
energy	
methods	equipment procedures
process engineering	reactors processing control
enzyme technology	screening production design
analysis	equipment procedures
bioelectronics	hardware software
risk assessment	

Figure 7

Source: Reiss et al. 1990

Figure 8

Figure 9

5. Literature

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