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Measurement of R&D Output Profiles: Conceptual Framework and 'State of the Art'

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Preface

This report has been produced as part of the preparatory work of NIFU's research programme "Profiling Output in Norwegian Research" and has to be read in conjuction with NIFU's report on "Output and Effects of R&D: A State-of-the-Art Study on Science and Technology Output Performance", skriftserie 19/98, written by Dag W. Aksnes. In Aksnes' report the reader can find a good overview of the kinds of bibliometric indicators that have been used to measure scientific performance at different levels (macro and micro) and on the main methodological problems attached to them.

The aim of the present report is to provide a *framework* to measure types of output in R&D organisations based on a review of previous studies on R&D outputs. The study is meant to be the starting point of NIFU's research efforts to understand production processes in Norwegian R&D institutes.

The author thanks *Karl Erik Brofoss* senior researcher at NIFU who supervised the design and the implementation of the project. Without his decisive contribution with original ideas and comments on the various drafts of this report, it would have been difficult to finalise this work.

Thanks are also due to *Professor Arie Rip*, University of Twente who commented upon an early version of the report and inspired us with his knowledge and kind nature. It was also on his suggestion that we embraced the idea of introducing the model of 'research compass' in this work. Many thanks also go to the rest of the group working in NIFU's programme for their support and to Sue Ellen Walters for her editing advices. And at last but not least, we thank the Research Council of Norway for funding this study.

Oslo, December 1998

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1 Introduction

The aim of this study is to provide a framework to measure types of output in R&D organisations. The study is meant to be the starting point of NIFU's research efforts to understand production processes in Norwegian R&D institutes.

Measurements of output of an R&D organisation should be related to the nature of R&D activities performed at the organisation and should be contextualised by linking output measures to internal and external characteristics of the organisation. Funding patterns, steering mechanisms, institutional strategies, interactions with other organisations and changes in policy environments all shape the output performance of an R&D organisation.

The key concept in this study is 'output profile'. By this we mean sets of indicators which measure different types of research results at the various levels of a research organisation. These sets of indexes should be integrated metrics that combine multiple objective ('hard' indicators) and subjective ('soft' indicators) measures of R&D outputs. The idea is that output profiles defined as complex multidimensional indexes may allow analyses of the R&D production process by also taking into account important contextual factors. The underlying assumption is that isolated metrics of some types of output, such as, publications or patents provide a limited picture of R&D production in complex R&D organisations as is the case for Norwegian R&D institutes. These organisations have different research areas, different missions and, thus, different output profiles. Thus 'soft information' has to be taken into account in measurements of output and of variations in R&D performance.

Given this assumption, the goal of this study is to present an analytical framework for measurements of R&D outputs in R&D organisations and to describe some measurement efforts identified in the literature of R&D performance. We shall focus particularly on studies where experience on measurements of various types of R&D output has been documented and discussed.

1.1 Conceptual choices and delimitations

In the study we focus on *R&D outputs* rather than on *the effects/impact of R&D* activities. There are three reasons for this artificial separation between R&D outputs and R&D effects. The first two relates to the well-known methodological difficulties in tracing the effects of a particular research activity. More concretely, there are two major problems in any assessment of the effects of R&D activities:

- The problem of 'attribution', that is, the attribution of particular economic (but also social) effects to a particular unit of research is difficult as products and processes draw upon a wide base of research and one unit may contribute to a number of different effects (Georgiou L. & F. Meyer-Krahmer, 1992). Successive attempts to calculate the rate of return of a particular project in various evaluations have not been successful. The main reason for this failure is that the rate of return of R&D activities can be calculated on the basis of the entire R&D costs of a firm, since it is almost impossible to separate knowledge generation taking place within a particular project from other skills generated in other circumstances within and outside the walls of the R&D organisation participating in the evaluated programmes.

- The problem of 'intermediators', that is, successful innovation and commercialisation necessary to realise the benefits of R&D. These require complementary inputs such as management skills, investment capabilities and marketing expertise.

A third problem relates to the fact that R&D productivity is, in principle, a managerial issue for any R&D organisation. Some of the identified factors shaping R&D productivity in R&D organisations are: the R&D organisations's base of knowledge, the timeliness of the efforts, the thoroughness in project planning, and the effectiveness in staffing (see Werner B.M, W.E. Souder, 1997). All these factors refer to internal R&D management practices.

Impact, on the other hand, is a consequence of complex dynamics often lying outside an R&D organisation. In fact, we still know little (lack of sound theoretical foundation) about how R&D outputs (micro and meso levels) are turned to effects (meso and macro level).

Our belief is that a step towards a more theoretical understanding of the relations between *outputs* and *effects* presupposes a thorough investigation of what the concept 'output profiles' implicates. How is it possible to identify and measure their variations in a meaningful way and how are these variations related to R&D organisations' internal features, managerial skills, thematic orientations, etc..

R&D outputs are not only scientific publications or technological artifacts. One should keep in mind that some of the principal results of research efforts are intangible, for example complex *knowledge flows* created between R&D institutions, users, research organisations, public services, etc. In other words, heterogeneous interaction patterns of R&D organisations and other intangible outputs should be at the centre of a study of R&D output profiles.

A description of the chapters in the report is given below:

In Chapter 2 we provide some arguments for why it is important to focus on output profiles in Norwegian R&D institutes. The Norwegian R&D institutes (non-university research institutes) has particular status in the Norwegian research system. In order to understand the role of these institutions, we need to understand what they produce and how this production relates to their unique characteristics.

Chapter 3 suggests an analytical framework for addressing the question of how to make typologies and measurements of R&D outputs. The principal model of this chapter is the 'research compass'. This is a modified version of the original idea presented in the Joint EC - Leiden Conference on Science & Technology Indicators, in 1992 by P. Laredo (et al.). We argue that the four dimensions of the 'research compass' provide a framework to operationalise the concept of 'output profile' as an element of the more general 'institutional profile' of an R&D organisation.

Some of the main types of R&D output with an overview of previous studies done in this area in Norway are discussed in Chapter 4. The presentation is based on the analytical framework of the 'research compass'.

In Chapter 5 we provide some conclusions drawn in this investigation. Here we primarily identify areas where further research is needed.

2 Why focus on Norwegian R&D institutes?

The research laboratory or the research group is the basic unit of scientific production. At this level, studies have been done on research performance, efficiency, collaboration patterns etc. The basic unit is considered to be capable of autonomous strategies, that is, defining research themes, setting priorities and in some instances political goals at the macro level. It makes up a codified framework of researchers, technicians, instruments and materials which allows collective learning processes to develop. This also allows the accumulation of tacit knowledge, an important element of competitive advantage in modern knowledge economies (Laredo P. et al. 1991). In this study, however, we focus on the institutional level, which may contain several such production units. The main reason is the fact that they constitute the administrative unit for which strategic plans and instruments have been developed and applied in Norwegian research policy. In the following, we shall present some rudiments of what we define as ‘the Norwegian R&D institute sector’ and what kind of research policy instruments have been used to control research activities in the sector at the national level.

2.1 R&D Institutes

The *Norwegian research system* is divided into three sectors performing Research and Experimental Development (R&D):

- *Industry Sector*, which encompasses companies, i.e. units which produce goods or services for sale on the open market

- *Higher Education Sector*, which encompasses universities (incl. university hospitals), university colleges, and state colleges

- *Institute Sector*, which encompasses research institutes and other R&D-performing units not included in the two above sectors.

In international R&D statistical terms the *Institute Sector*[1] covers units from the Government and Private Non-Profit Sectors, and also non-profit institutions performing R&D within the Business Enterprise Sector. Quantitatively speaking the Institute Sector had an R&D turnover of approximately 4.8 billion NOK, which is slightly more than one fourth of all R&D performed in Norway in 1997.

[1] For a more in-depth presentation of The Institute Sector in Norway see NIFU, 1998.

Our main focus in this study, however, is on the subgroup within the Institute Sector, denominated *R&D institutes*, i.e. units which have R&D as their main activity. By confining ourselves to these approximately 60 institutes, which made up 80% of the total R&D performance in the Institute Sector in 1997, we eliminate several other units encompassed in the Sector. The latter do R&D, but not as their main activity, and typically R&D makes up a smaller share of their total activities. Examples are national administrative agencies, branch organisations, hospitals and museums.

There are several ways to classify the R&D institutes. One way is to use the official distinction between five groups, applied in national policy towards R&D institutes.

- Industrial research institutes[2]
- Agriculture and Fishery research institutes
- Environment and Development research institutes
- Medicine and Health research institutes
- Social Science (incl. Regional) research institutes

The policy making for the R&D institutes, e.g. guidelines for Government funding, has increasingly become a responsibility of the Research Council of Norway (RCN) during the 1990s. The responsibility, however, ranges from advising ministries on institute matters to more or less autonomous budget decisions regarding the allocation of funds between institutes. There are variations between and even within ministries and the RCN, regarding the distribution of responsibilities. The policy making includes three types of steering instruments:

1. Decoupling them from state ownership and providing them with greater autonomy but also greater responsibility for their own development

2. Designing research programmes for targeting the type and nature of long term research activities of the R&D institutes

3. Connecting the R&D institutes to networks of other national and international research organisations and users

[2]For a detailed presentation of this group of research institutes see Norges forskningsråd, 1997. In this report, The Norwegian Research Council presents input and output statistics of 15 different industrial R&D institutes. Especially the output statistics in the report are relevant to this study. These statistics are an important contribution towards the construction of more complete output profile indicators.

How can we study the effects of these instruments on the research content and on the research organisation of individual institutes? What data and methods do we have to develop for doing this? These questions are also related to what are perceived as the main policy challenges in the future. What kind of information do we need in order to monitor key aspects of institutional developments which correspond to these challenges?

2.2 Policy challenges related to R&D institutes

The main challenge of Norwegian R&D institutes is to develop their role as producers of new scientific, technical and applied knowledge and to qualify as networking organisations responsible for the diffusion of new knowledge to national industry and to the public sector. This is not an easy task in a system of rapid change.

We distinguish between three types of challenges:

1. Challenges related to the *efficiency* and *effectiveness* of R&D institutes in the context of *liberalisation* and *internationalisation* facing many countries the 1980s and 1990s.

2. Challenges related to the role of Norwegian R&D institutes in the national research system as a whole.

3. Challenges related to the future orientations of individual R&D institutes.

2.2.1 Efficiency and effectiveness of R&D institutes in a changing research system

Many studies in the past 10 years examined policy questions related to national systems of innovation (see for example Lundvall B.A., 1992, Nelson R.R, 1993). Fewer studies, however, investigated questions of relevance, efficiency and effectiveness of R&D institutes in the context of liberalisation and the internationalisation of research.

Unlike firms, R&D institutes cannot be assessed on the simple basis of market shares or profits. Unlike, academic departments, R&D institutes can also not be assessed on the simple basis of scientific production (measured as number of publications, number of citations, etc.). Therefore, the criteria of success in the case of R&D institutes should be a combination of dynamism, relevance to their users, contribution to national science and technology infrastructure, value for money, independent fund-raising capability, innovative organisational approaches, effective management and solid scientific and technological outputs (Rush H. et. al., 1996, p.3).

In order to find an effective role in national research and innovation systems, R&D institutes need to be seen as an integral part of the system's innovative potential. That is, one has to consider the set of interrelated components which work together to give rise to the overall performance and behaviour of the system. In other words, the roles played by individual institutes mirror and support differences between national systems. Thus, interrelations become a key issue in the assessement of effectiveness of the Norwegian R&D institute sector, since these determine the functionality of the R&D institutes and the manoeuvring possibilities an institute have in case of a reorganisation. Therefore, differences in project portfolios and output profiles has to be assessed in relation to the particular context of R&D institutes. Now, this is an extremely difficult task because there is neither a solid information system nor a theoretical framework enabling us to combine issues of effectiveness and efficiency at the micro level to issues of functionality and systemic interaction at the macro level. This lack of theoretical and methodological tools represents a genuine challenge for research policy thinkers.

2.2.2 R&D institutes and their role in the Norwegian research system

Taking into account the discussion above, one should keep in mind that R&D institutes are particularly important in the Norwegian case, since they perform more than 30 per cent of all R&D activities in the country. Their main role is primarily to function as mediators of knowledge between the international and national research fronts and the national economic or political institutions.

General changes in the global research environment, however, put this function under pressure. One the one hand, universities have increased their share of external funding and have thus become able to compete with R&D institutes in many different economic and public sectors. On the other hand, consultancy firms and other service organisations have increased their influence and they often employ highly competent researchers and engineers from R&D institutes. All this makes the demarcation of roles between the different knowledge producers and between knowledge producers and knowledge consumers less clear and less manageable.

2.2.3 Specific challenges to individual research institutes

The management of research differs greatly according to size, sector position, complexity of structure, user demands and the available scientific and organisational competencies. However, in their study of success factors of nine technology R&D institutes from different countries, Rush H., M. Hobday, J. Bessant, E. Arnold, R. Marray, (1996), identified the following key factors determining success:

- Management of the risky nature of R&D activities
- Balance between large and small customers
- Balance between hard and soft services
- Balance between public and private funding
- Personnel and leadership policies

In a word, balancing between research, development, other services and diffusion activities represents a major challenge for all modern R&D institutes. We believe that quantitative studies of institutional profiles may provide valuable knowledge about how the Norwegian R&D institutes cope with these tensions at the institutional and at the research group level.

However, there are some particularly sensitive success factors for an R&D institute which cannot be sufficiently studied with quantitative analysis. One of these factors is the managerial decisions on research direction and their relation to the core competencies and skills of the organisation.

Prahalad and Hamel (Prahalad and Hamel, 1990) defined core competencies as:

- Core competence gives the enterprise access potentials to numerous markets
- Core competence should contribute substantially to the usefulness of end products to customers.
- Core competence should be difficult for competitors to imitate.

The Prahalad-Hamel concept 'core skills and competencies' is developed mainly for the R&D activities of private enterprises. As R&D institutes function in a more liberalised research environment, they may have to define what their core competencies are for their long-term plans in order to be more efficient and more attractive partners in a national system perspective.

Such strategic thinking presupposes, however methods to measure and monitor knowledge production and knowledge management in R&D institutes. That is:

- What are the knowledge and skills of employees (scientific understanding, technical expertise, project experience)?
- What kinds of knowledge acquisition (new people attached to the institute, training, collaborations, etc.) and knowledge control (report systems, incentive systems, career planning, etc.) exist in the individual institutes?
- How is the intangible 'tacit knowledge' of employees organised at which level of the organisation?

These questions are by no means trivial for the managers of R&D organisations or for research policy makers.

Measuring R&D output certainly do not give answers to all these questions (challenges) mentioned in this chapter. Yet, we believe that understanding what a

R&D institute produces is an essential step towards more thorough analyses on those matters.

In the next chapter we provide an analytical framework for measuring R&D outputs.

3 Dimensions of R&D output

Measurement techniques of R&D output were mostly developed in the evaluation practices of R&D programmes which took place in the late 80s and 90s. These evaluation practices based mainly on peer reviews supplemented by bibliometric evaluative techniques were (and still are) focused the "quality of research" conducted in a research institution and occasionally also on aspects of research management. However, research in these R&D institutions should first and foremost be useful to, and appropriated by, national industry and the national public sector.

Therefore, there is an increasing need for methods to assess research output in relation to functions of R&D organisations, such as:

- Institutional missions in respect to their legitimacy and relevance
- Research management issues (knowledge management, research efficiency and effectiveness)
- Research targets and alternative options
- Client networks and client relevance

Assessments of organisational performance in respect to these functions require both workable conceptualisations, good measurement methods and available data sources. In the following we introduce the concept of 'institutional profile' in order to provide a framework for seeing R&D performance in relation to the above mentioned functions of R&D organisations.

3.1 What is an 'institutional profile'?

One of the objectives of any performance assessement should be to profile production in R&D institutes within the (functional) *context* they belong. An institutional profile should, therefore, include:

1. Information about institutional resources and funding structure

2. Information about research, personnel, knowledge and intellectual capital management as well as information about strategic choices and priorities of the different levels of the R&D organisation (research groups, research units, labs, other units, directors)

3. General information about the structure and the dynamics of the R&D areas where the institution under scrutiny is involved

4. Information about the role of the research institute in the knowledge system of the region and of the country

5. Information about R&D results including information about the users of the results and about all interactions enabled by the R&D activities of the institution.

All these five elements are intertwined and we obviously need both quantitative and qualitative information in order to capture them.

Statistics about resources, though attached with some methodological problems, are, often available. In the case of Norway, there is fairly detailed information about the resource situation of the most important Norwegian R&D institutes Key indicators survey in the institute sector) for the years 1993, 1995 and 1997.

Information about management issues, dynamics of R&D areas, roles and missions of R&D organisations is typically of a qualitative nature. With this information it is possible to understand the particularities of R&D organisations There are no standard methods or well-established routines on how to systematise these contextual aspects for a more thorough understanding of the production processes within R&D organisations. Evaluation reports, annual reports, home pages on the Internet and archives of R&D organisations are the main sources of information used for this purpose. In general, qualitative presentations of R&D organisations is an area monopolised by historians and to a lesser extent by operational analysts with interests in R&D evaluation methodologies.

An interesting attempt to compare the institutional profiles of nine technical R&D institutes embedded in different national R&D systems and different political regimes may be found in Rush H. et al., 1996, *Technology Institutes: Strategies for Best Practice.* In this work contextual elements such as historical trajectories, missions and politico-economic regimes are explicitly taken into the analysis.

The last of the elements of an institutional profile, that is information on R&D output, represent one of the major challenges in the area of research studies. Information about R&D output is usually scarce, fragmented and badly structured in respect to the needs of R&D management and research policy makers.

Some of the main shortcomings of existent R&D output indicators can be singled out:

- R&D output indicators are mostly available at a macro (national) level
- R&D output indicators are often not weighted or measured together with R&D input-indicators
- R&D output indicators are not coupled (or modified according) to contextual aspects of R&D organisations which are important in the production of R&D outputs.
- R&D output indicators are biased towards measurements of a limited number of functions of an R&D institute. This applies especially to the predominance of bibliometric metrics, that is measurement of various aspects of the production of scientific publications

In other words, improved R&D output measures should:

- Reveal particularities of various R&D organisations. That is to say, good R&D output measures should account not simply for differences of performance, but for differences of performance *given* significant differences of institutional profiles.

- Measure performance in all important functions of the R&D organisations.

These requirements lead us to a discussion on what are the appropriate *dimensions* across which one may introduced metrics of R&D outputs with respect to differences of institutional profiles and to differences of roles in the national R&D system. This is the task of the next section.

3.2 Relevant dimensions for measuring R&D output

R&D organisations can cover a wide range of activities which include research, development, knowledge and technology diffusion, services to industry or to the public sector, policy advice, regulation, manpower training, etc. In order to adequately understand the R&D component of institutions such as Norwegian R&D institutes, all types of activities have to be taken into account. The assessment of such multi-functional institutions cannot rely on a single output indicator such as publication activity or citation rates. This is why a set of different indicators is needed.

The set of indicators measuring different dimensions of R&D results is defined here as the ‘output profile' of a research institute. Such indicators presuppose access to different data sources, the creation of new indicators and the combination of quantitative techniques. But the very first prerequisite for a *fair* measurement of 'output profiles' is the design of a *sound and workable definition* of output dimensions suitable for measurements of production processes in R&D organisations.

During this project we searched for workable conceptualisations of R&D output dimensions. This search led to the identification of a particular line of work which seems to provide an adequate typology for the needs of this programme. This is the work of P. Laredo et al., 1992, on 'the research compass card' at the *Centre de Sociologie de l' Innovation* in *Ecole Nationale Supérieure des Mines* in Paris.

The main idea behind the 'research compass card' is to encompass five output dimensions attached to different arenas in which the *unit of research production* (in our case the R&D institute) simultaneously inscribes its activities. The unit of research production may be a research laboratory, a research group, a research institute or section of a research institute, etc. Its definition as a unit of research production depends on whether:

- The unit is capable of *autonomous strategies*

- The unit constitutes a codified framework which makes the production of results difficult to obtain otherwise. In addition, it fosters the accumulation of *tacit knowledge*

In contrast to studies of output production in firms, which basically are subjected to only one evaluation criterion, their ability to make profits, a unit of research production operates in a multiplicity of contexts and regimes, each one with different evaluation criteria, and hence with different relevant output measures. The idea behind the concept of the 'research compass' was precisely to offer a method which "simultaneously and symmetrically takes these different regimes into account"[3].

Laredo et al. distinguish five different arenas with their respective types of outputs. These are:

- The scientific arena and the production of certified knowledge

- The education arena and the creation of skilled manpower and embodied knowledge

- The techno-economic arenas and the creation of innovation

[3]See Laredo P. et al. (1992), p. 185.

- The arena of the public sector and the production of knowledge for the achievement of public goals

- The arena of public understanding and awareness through media and public forums of research and the creation of trust, scientific expertise and attitudes towards science and technology.

For the purposes of this programme, we find it sufficient to integrate the last two dimensions into one. That is, the output ‘research compass’ of this programme comprises four arenas (or regimes). Before giving a brief account of these four arenas and their respective outputs, it is necessary to provide two methodological clarifications of importance for understanding this programme.

First, the artificial separation of the different research arenas listed above is not only introduced for analytical purposes. We have stated that the interactions between any research unit and its arenas develop simultaneously. This does not mean, however, that monitoring the development of the research unit across the different dimensions of the ‘research compass’ should lead to a unique metric because of this simultaneity. On the contrary, putting together indicators derived from evaluation criteria of the performance of the research unit in the different arenas should be sufficient to construct non-redundant ‘output profiles’ . This is why the ‘research compass’ is a conceptual tool for constructing *good* ‘output profiles’.

Second, within each one of these arenas there are some ‘rules of the game’, that is, some evaluation criteria and co-ordination mechanisms specific to each ‘research compass’ dimension. This enables us to search for possible output indicators which have to reflect the embodied rules and production processes of the specific arenas. This also implies that one should have a reasonably good understanding of the rules and interaction mechanisms established in the different arenas for the identification and measurement of relevant output indicators. Figure 1 below shows the four arenas of the ‘research compass’ and their respective output dimensions.

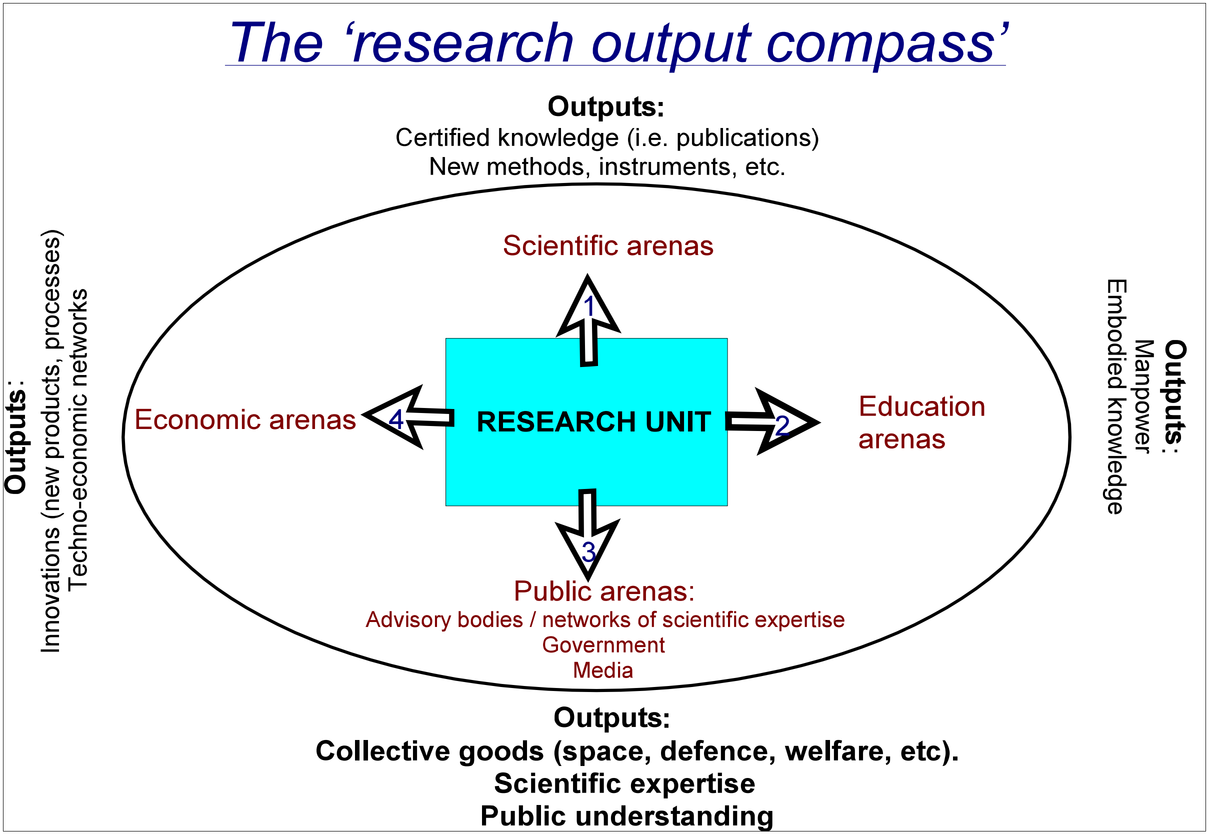

Figure 1: The 'Research OUtput Compass'. Modification of the 'research compass' model in Laredo P (et al.), 1992.

Dimension 1: Research arenas and the production of certified knowledge

Research is supposed to contribute to the production of new scientific knowledge. The production of new scientific knowledge takes place in complex communication channels between researchers. This communication is both stratified and structured. The publication of articles in 'refereed' journals is, perhaps, the most stable communication channel in research where both the mediation and the quality control of scientific knowledge are realised. Bibliometrics has shown that there are surprisingly stable patterns of scientific productivity (measured as counts of publications or citations). These distributions enable us to develop measures for characterising the certified scientific production (that is publications and, perhaps, instruments) of a research unit and, hence, assessing its scientific performance.

Dimension 2: Research in education arenas and the creation of embodied knowledge

Enabling society to absorb research results is not the same as producing and circulating them. Heavy human investments are needed for building up competencies and in the literature there are indications of a strong relationship between the efficient dissemination of research results, innovation activity in society and good management of human capital. Hence, the production of 'embodied' knowledge and skills in academic arenas appears, thus, an important output dimension.

Dimension 3: Research in public arenas (public activities and public understanding)

So far little seems to have come out of efforts to develop general indicators about societal research output in a broad sense, whether that is understood as the "quality of life", including health; the quality and characteristics of nations´ environment, culture, public decision processes or political debate. Undoubtedly, research does produce results that through some not well-understood mechanisms and interactions affect society within all these social dimensions in specific ways. Understanding the nature and the function of these mechanisms must generally draw upon in-depth studies of specific societal sectors and cases. At the moment there is apparently no approach in international research on R&D output that addresses these issues in ways that may lay claim to represent an *established set* of methods in this output dimension. There is, however, one exception; this is the "public understanding of science and technology" surveys, developed within the framework of the *US S&T Indicator Reports.* Still, even in the area of the "public understanding of science and technology", there is a lot of work to be done before one can use these surveys as output indicators of particular research organisations.

Dimension 4: Research and the innovation process

An important dimension of output for a research unit is the creation of competitive advantages, that is, the process of the transformation of public knowledge and 'embodied' skills to proprietary knowledge. This transformation process takes place either in networks of knowledge users and knowledge producers (downstream knowledge diffusion) or in networks of co-producers of knowledge or by the production of disembodied knowledge in the form of artifacts. Perhaps the most obvious example of transformations of proprietary knowledge is the production of patents. Examples of production of disembodied knowledge are the construction of prototypes, technological products or processes and experimental testing. In the case of Norwegian R&D institutes, one way to trace their intangible contribution to the creation of competitive advantages is to follow the development of links between R&D institutes, universities and private companies apart from their production of patents, products, pilots, etc..

In general, output measures across the four dimensions of the 'research compass' allow appreciation of the performance of R&D organisations in each of the different contexts. i.e the four dimensions.

We emphasise that the 'research compass' framework is compatible with the idea of 'output profiles'. Concretely, the strength of the 'research compass' as an analytical framework lies in the fact that putting together indicators derived from the measurement of the organisations' outputs in the four different contexts may be used as:

- A framework for benchmark comparisons of *research efficiency across* one (and the same) dimension of the 'research compass'

- A framework for identifying *output profiles*, that is, the composition of the output performance of each R&D organisation across the four dimensions of the 'research compass'

- A framework to reveal previous strategic choices and research orientations traced by the quantity and composition of the outputs in the dimensions of the 'research compass'. In that respect, aspects of the overall *institutional profiles* of the R&D organisations can be encapsulated in the output profiles of the R&D organisations.

In the perspective of the 'research compass', traditional definitions of university departments (that are supposed to produce only certified knowledge) or of industrial R&D units (that are supposed to produce only marketable knowledge for the interests of the company) appear as oversimplifications. That is, they appear as if R&D organisations contribute to only one of the four dimensions in the 'research compass'. As we already argued in Chapter 2, the functions of the Norwegian R&D institutes are multiple and cover all dimensions of the 'research compass'. Hence, we believe that the analytical model provided by the work of Laredo (et al.) is a fruitful starting point for further studies of R&D outputs.

In the following chapter we shall attempt to systematise experiences related to measurements of various types of R&D outputs structured by the analytical framework of the 'research compass'.

4 Types of R&D output

In this chapter we shall present some studies on measurements of various types of R&D output. The idea is to use the 'research compass' model (see Chapter 3) for a more structured presentation of this literature. The 'research compass' model enables us to identify how indicators of different types of R&D output cluster around the four dimensions of the 'research compass'. We conclude the chapter by noticing that measurement methods of the economic and scientific types of R&D output relevant for the construction of output profiles for Norwegian R&D institutes are best studied in the literature and that we practically have no indicators for measuring the R&D outputs in the public/social dimension of the research compass. This is a serious deficit of methods if one considers that the majority of the Norwegian R&D institutes have public services as their main users.

4.1 Research arenas and the production of certified knowledge

4.1.1 Production of new scientific knowledge, methods, instruments

Perhaps, the most important outputs of a research activity are the new contributions to the existent scientific knowledge base. What kind of new scientific or technological insights (theories, methods, instruments), new methods, new hypotheses are the output of research activities of a particular research institute? Direct aggregate measures of this type of output are scarce. Of course, publications, especially publications in international journals with referee procedures, are regarded as the main carrier of information of new scientific knowledge and capabilities. Citation counts often serve as an indicator of the importance and attractivity of the new scientific insights documented in scientific publications. Yet publications do not always capture the totality of knowledge production originating from applied research institutes. In fact, we know little about the proportion of new scientific knowledge produced in R&D institutes which escapes publication. This is an empirical study which should be conducted in the case of the Norwegian R&D institutes. Another problem related to the use of publications for the identification of the creation of new research insights is the time lag between the ongoing research activity and the publication of scientific results. It often takes 1-2 years before a paper gets published. It takes even more time before the published papers get cited. This means that bibliometric methods cannot capture the changes of direction and the novelty (as well as attractiveness) of the research activities before 2-4 years. From a research policy perspective this is often a long time span.

Some impact studies and evaluations of research programmes attempt to capture the magnitude and the importance of the creation of new knowledge as a research output in a set of survey questions (see for example Hagen I., (1997), Evaluation of the JOULE programme (1994), Evaluation of the ECLAIR and FLAIR Programmes (1995)). The general impression is, however, that no systematic registration of this crucial aspect of output has taken place.

4.1.2 Publications

Scientific publication output and citation counting are by far the most common and most explored data of research output. Bibliometric methods are almost exclusively based on the study of *scientific publications in international scientific journals*[4].

However, *other types of publication output*, such as, books, reports, working papers, etc. are seldom studied as research output by bibliometricians. This is one of the reasons we still know little about the role of these publications and their value in the knowledge diffusion processes. These publications are, perhaps, not the most significant output in the case of traditional disciplinary research. But as the production of knowledge becomes more complex, and the interactions with non-academic institutions are intensified, the mode of knowledge production has the tendency to be less ‘academic' and, therefore, less transperant and accessible. Hence, non-scientific journal literature, especially internal working papers and reports may be more important output than has been assumed hitherto. This type of output is obviously more important in the case of R&D institutes compared to university research.

In the 1998 key indicators survey on Norwegian R&D institutes, the Norwegian Institute for Studies in Research and Higher Education (NIFU) included for the first time questions about non-international scientific journal publications and about the number of seminars and conferences organised by the institutions. This information permits the construction of an institutional publication index comprising different types of publications ranging from publications in top (influential) scientific journals to particiaption in seminars and workshops. This index may reflect important aspects of organisational scopes and orientations which could not be captured by only focusing on publications in international scientific journals.

In addition, there is an intention to register all types of publications primarily originating in Norwegian universities (FORSKPUB project). This database can provide the empirical data for a study of the publication patterns of universities and, perhaps, later on of the research institutes. The FORSKPUB project is also linked to multinational collaboration projects at the European level such as EUROCRIS and CERIF aiming at the complete documentation of European publication outputs with research projects as the reference unit. In France, the INRA foundation has also

[4]In this study we shall not discuss bibliometric indicators. Despite the fact that bibliometric indicators still are by far the main instruments to measure scientific productivity impact, we choose to concentrate on other types of R&D output. For an extensive overview of R&D output indicators based on bibliometric measurements see the study of the Aksnes D, 1999 and Kaloudis, 1998. The study of Aksnes has been conducted in close collaboration with this study and, therfore, should be seen as complementary.

developed its own database where all publications from INRA R&D institutions are catalogued.

4.1.3 Research networks

Research networks have become a critical issue in modern research. The increasing complexity of research endeavours, with many and heterogeneous interactions, cannot be controlled by one research unit. Thus, network formation and the orchestration of its interactions is a way to an efficient organisation of complex (and often multidisciplinary) research. Therefore, in modern research policy, research networks are considered as an important R&D outputs in its own right.

Despite the difficulty of the matter, some studies have focused on the analysis of research collaborations, their typologies, their functions and their organisational features between researchers (Dahl M., S. Lahlou, 1991, Laredo P. et al., 1992, Laredo P. 1994, Melin G.,1997). Here, we shall only review two network studies considered relevant to a study of *collaboration patterns* of Norwegian R&D institutes as an aspect of their output profiles.

The study of Laredo P. et al. (1992) introduces a typology scheme designed for an analysis of *biomedical networks* funded by the MHR4 European Programme which was a research programme in the field of biomedicine in the European Union's Second Framework Programme. In the study, three criteria of network specification have been used:

Criterion 1: The composition of actors participating in the network (percentages of academic partners, service institutions such as general hospitals or health services and industrial partners).

Criterion 2: The organisational form of the concerted action: the study distinguished between thematically partitioned networks (organisation of activities into sub-networks co-ordinated by project co-leaders) , geographically partitioned networks (geographical organisation of activities with several national co-ordinators), star networks (where the action is organised around the project leader and his team) and the actions limited to the organisation of conferences, financial support for visits or small seminars.

Criterion 3: The activities of concerted actions: The study distinguishes here between forum networks (that is, arrangement of meetings for scientists to discuss their results), harmonisation networks (that is, exchange of data and materials, defining protocols and comparing scientific results between different partners), collection infrastructures (that is, systematic collection of data, which calls for the establishment of a "reference centre" to organise the collection process, manage the databases and take the responsibility for data processing) and instrumented networks (that is, networks in which partners make use of centralised facilities which direct members' activities). The instrumented networks especially require extensive logistical organisation in human, technical and financial terms, and this is often the main cost of the project.

The classification criteria applied in the Laredo study may also be operational in the analysis of collaboration patterns emerging in many Norwegian R&D institutes.

In Norway, Kaloudis A., (1995 and 1996) focused on the networking patterns of Norwegian R&D institutes based on co-authorships in scientific publications registered in the Science Citation Index (SCI) and the Social Science Citation Index (SSCI). In this work, all R&D institutes with at least ten papers in SCI/SSCI have been classified in five main thematic groups. Then, the co-authorships patterns of these five groups are studied. Though co-authorship analysis suffers from some obvious methodological shortcuts, since not all research institutes publish regularly in international journals, we believe, that it provides valuable and reliable information.

From a methodological point of view five different methods have been used to identify collaboration relations.

These are:

- Collaboration linkages in bibliometric studies based on co-authoship patterns.Most studies on collaboration patterns in research have applied bibliometric methods in their analysis (for a classical reference see for example T. Luukkonen et al.,1993.

- Surveys designed specifically for analysis of collaboration linkages (see for example Dahl M., S. Lahlou, (1991), Laredo P. et al. (1992))

- In-depth interviews designed specifically for identification and analysis of collaboration linkages (Callon M.et al. (1992)).

- Collaboration linkages through project co-participation (see for example Cabo P.G., T.H.A. Bijmolt, (1992)).

- Collaboration linkages through formal collaboration agreements (see for example Tijssen R.J.W. (1995)).

One of the challenges in studies of research collaboration networks lies in the combination of different information sources. This is, because different data sources often reveal different aspects of the complex and heterogeneous network patterns in modern research (see for example Tijssen R.J.W. (1995)).

4.2 Education arenas and the creation of embodied knowledge

4.2.1 The (co-)production of degrees

The production of Master and PhD Degrees is by far the most important output of universities and other academic institutions. In the case of independent R&D organisations, there are many R&D activities involving PhD students or leading directly to PhD degrees. This is obviously an important R&D result that has to be registered and analysed. In Norway there are available statistical data on how many researchers possess a PhD degree in Norwegian research institutes and data on how many of the staff members have had supervisor responsibilities for PhD students[5]. These types of data provide some indications of the degree R&D organisations are involved in the production of new researchers and new competencies both within and outside the institution. Despite this fact, there is no *comprehensive study* on how these institutes actually contribute to the overall production of formal embodied research knowledge in Norway.

4.2.2 Core competencies and skills

The continuous and formal upgrading of human capital within R&D organisations, is, perhaps, one of the most important determinants of R&D output profiles. How skills and competencies are related to the production of research within an organisation is a crucial question not only for the directors of a research institute, but also for policy makers at the national level. One of the challenges is to understand how the missions and the strategies of R&D organisations are directly linked to choices about what kind of new competencies and skills have to be developed within the walls of the organisation or acquired otherwise. *There are almost no statistics on this matter.*

There are also very few studies bringing up the question of documentation and measuring techniques of new competencies and skills in R&D organisations other than the registration of formal degrees and of longer-term research stays. Even this type of information is quite difficult to access.

Some theoretical and empirical work to this direction has been done however. One can mention the classical Prahalad C.K., Hamel G. (1990) study introducing the

[5]NIFU's statistsics on Norwegian R&D institutes. See also Norges forskningsråd, 1997. p. 67. In the later, the reader can find statistics on the number of PhDs and other students involved in the research of 15 industrial research institutes in 1997.

concept ‘core competencies' in a corporation and the managerial problems connected to this concept. Stillman H. (1997) presents how the ABB corporation uses ABB's evaluation strategies to identify holes of competencies in what are considered core technology investments in the company. L.P. Hughes and J.A.D. Holbrook (1998) present a methodology (survey) to investigate whether firms have institutionalised knowledge management practices and whether firms are prepared to take advantage of their human resource development efforts. These studies pave the way for future theoretical and empirical work on the question of managing human capital in knowledge- intensive organisations, but they provide few guidelines about how to proceed in measuring new types of competencies gained in a research institute.

A significant conceptual contribution towards a system of documentation and registration of core skills and competencies in research has been done in the Norwegian project ‘A common national system for research documentation' (Hauge J.H. et al., 1996). This project resulted in an official proposal for a common national system for research documentation. In this proposal competencies are defined mainly on the basis of individual researchers' formal academic credentials, educational experience, personal research interests and expertise (Hauge J.H. et al., 1996, p.38). The numerous links between data on competencies and other institutional and project related variables provide interesting opportunities to study the development of competencies within and between R&D organisations. This system is primarily designed for the documentation of research activities of universities, but it can easily be applied to the needs of R&D organisations. However, there are a lot of technical and institutional obstacles before this system can be fully operative.

4.3 Socio-economic arenas and the innovation process

4.3.1 Patents

Patent statistics are mainly utilised to proxy the results of technically oriented inventive activities. Patent counts make up the basic dataset for most patent analysis and are widely used, notably at the national level. The pure enumeration of patent applications and patent grants by technical organisations has been applied in the identification of technological competencies of nations, industrial sectors and firms in industrial sectors (see for example Archiburgi D. and M. Pianta, 1996 and Joly P.B., M.A. de Luoze 1996). In some studies patent counts are weighted by the citations the patents received by other patents as a proxy of patents' value (see for example M. Trajtenberg, 1990). Patent citations have been also applied in order to establish linkages between basic research (scientific publications) and patents via the citation a scientific paper receives from a patent (see Carpenter M. et al., 1980). In an original study, Adam B. Jaffe compared the geographic location of patent citations with that of the cited patents, as evidence of the extent to which knowledge spillovers are geographically localised (Jaffe A.B. et al. 1993).
In Norway there are few studies on Norwegian patenting activity. It is known that Norwegian research institutes do have a limited propensity to patent in the US Patent Office or in the European Patent Office - EPO (see for example Iversen E., 1997). We know, however, little about the patenting behaviour of the R&D institute sector in the national patent office (Patentstyret). Patents are important indicators of measuring aspects of R&D activities of R&D organisations. They are also important data sources for the analysis of technological research in the Norwegian institute sector. It is especially interesting to investigate 1) how many patent applications and patent grants the Norwegian institute sector produces as one of the elements of the institutes' output profiles 2) the role of the R&D institutes (especially the technological R&D institutes) in Norwegian patent behaviour.

4.3.2 New products, processes, softwares, other intellectual property rights

Other direct results of research activities may be new guidelines for standards, new prototypes, new software, new products and new processes. These types of output have attracted a lot of attention the last years, particularly in the core of innovation studies literature. Several databases has been created to register these types of outputs at a project and programme level (but not necessarily at an institute level). Especially in the European Union's technology oriented specific programmes and in the diffusion activity INNOVATION, much work has been invested in the creation of new databases for the registration of the number of these kinds of outputs attributed to the project level of the EU's R&D programmes. How this information has been used, or will be used for analytic purposes, remains an open question.

When it comes to studies on *intellectual property rights as R&D outputs results*, the Statistics of Canada recently commenced a survey of intellectual property commercialisation in the Canadian Higher Education Sector. In the survey designed by Statistics of Canada, it is asked, among other things, whether the institutions have an infrastructure for intellectual property management, who owns the rights to the invention (the institution, the researcher or the research contract sponsor) and what is the role of research contracts when it comes to the protection of intellectual property rights. In addition, there are questions on patents and licences obtained by an institute, royalties received, educational materials, industrial designs, trademarks, etc. The Statistics of Canada investigation is certainly an interesting example of methodologies about collecting information on intellectual property rights production. The same methodology can also easily be applied also to intellectual property commercialisation studies in Norwegian R&D institutes.

4.3.3 Mobility of researchers

One important output of research is the provision of trained research personnel who go on to work in other places (private or public sectors, universities or other R&D institutes). These researchers take with them not just the knowledge resulting from their research within an R&D institution but also skills, methods, and a network of professional contacts. This is often not only to the benefit of the organisations these people are moving to, but also an advantage of the research institutes themselves. This is why we count the mobility of researchers as an output variable.

There is an increasing number of studies on mobility patterns.

An important contribution to the study of mobility of human resources in National Systems of Innovation may be found in a joint effort of Norway[6], Finland and Sweden, aiming at the mapping of mobility patterns in the three countries (see Nås S.O., et al., 1998). In this work, formal competencies in the innovation systems of the Nordic countries are analysed based on register data. The study investigated to what extent register data on employees can be utilised to study stocks and flows of personnel in a national innovation systems perspective. The registers contain information on each single employee in the three countries in the study (Sweden, Norway and Finland), including information on their *age*, *education* and *employment* at any particular time. This information is used partly to compare stocks of employees with different types of education across industrial sectors, and partly to describe flows of personnel between sectors. In the sectoral breakdown of the analysis, a particular attention has been given to *higher education institutions and research institutes*. Some of the methodological problems of comparative analysis of mobility patterns between countries relate to differences in

[6]See Ekeland A., 1994. In this early study, the Norwegian mobility patterns in the Norwegian private sector are mapped and measured.

industrial structures and education systems, with the resulting problems of coding and updating of registers. Despite these problems it seems that Nås S.O. et al. presents a reasonable picture of mobility patterns in Nordic countries. This overall picture of national mobility patterns enables a more detailed (and comparative) analysis of mobilty patterns in the Norwegian research institutes.

Another recent study provides an overview of mobility patterns in Norwegian R&D institutes for the period 1989-1993 and a comprehensive reference list over previous work on mobility issues in Norway (Tvede O., B. Sarpebakken, 1998, pp. 35-38). According to this study, there is a limited propensity to shift workplaces among researchers in the Norwegian institute sector. When this happens, it is often to work primarily at universities (9 per cent of all individuals who worked in the Norwegian institute sector in 1989 and changed their workplace in the period 1989-1993) and to the private sector (8 per cent) and secondarily in the public sector (4 per cent). An exception to this pattern is, perhaps, the group of R&D institutes in social sciences, where researchers move more often either to universities (15 per cent) or to the public sector (7 per cent). The data source of the NIFU study is based on the combination of two different nationwide databases. In the future it may also be possible to present more dynamic aspects of mobility patterns in Norway.

An additional information source for the registration of recent mobility patterns in R&D institutes (as an element of institutes' output profile) is the statistical data available in the 1998 survey on key indicators of the Norwegian institute sector (sixty-two R&D institutes)[7].

We still understand little about what types of ‘tacit knowledge', competencies and skills are transferred with the relocation of researchers from the institute sector. Movements of researchers from R&D institutes to the university sector, industry and public sector should be investigated in a more qualitative manner in order to understand what the sheer numbers of movement from R&D institutes really means and which factors condition this movement.

4.3.4 R&D organisation - industry linkages /networks

In modern technology policies, R&D networks are a goal by themselves. This is so because it is believed that the good organisation of networks in R&D is a crucial throughput in the research production process which enhances creativity, productivity and enables knowledge flows between the participants of the networks. In short, it is assumed that well-organised network linkages between research organisations and industry enable the efficient generation and diffusion of new knowledge. Thus, R&D networks within R&D organisations and between firms and R&D organisations are,

[7] see also Norges forskningsråd, 1997, pp. 62-63.

perhaps, the principal way to facilitate and intensify knowledge flows between research organisations and other private companies.

Numerous studies have focused on the analysis of such heterogeneous collaborations, their typologies, their functions and their organisational features (Callon M., et al., 1992, Hicks D.M. et al., 1996, Laredo P. 1994, von Bandemer S. et al. 1996). Here, we shall only review a very limited number of network studies considered relevant to a study of *collaboration patterns* of Norwegian R&D institutes as an aspect of their output profiles. The reviewed literature presented here focuses basically on the question of typologies of collaboration networks and not on questions of the management of knowledge production or diffusion in collaborative R&D.

Hicks D.M., P.A. Isard, B.R.Martin, 1996, examined the research output (measured in number of scientific publications) of thirty-four major Japanese and European companies in the pharmaceutical, chemical-pharmaceutical and electronic sectors. Then, they compared patterns of research collaboration (identified in co-authored publications). With this methodology they found that European firms collaborate in 52% of their papers with other R&D organisations, while Japanese firms collaborate in 33% only of their papers. Such a quantitative study could also be applied in a study of publication performance of Norwegian companies with a subsequent analysis of collaboration patterns with universities and Norwegian R&D institutes.

The study of Callon M. et. al. (1992) introduces us to the concept of '*techno-economic*' networks. This concept provides an analytical concept better adapted for studies of the relationships between research, technology and the market. Techno-economic networks are co-ordinated sets of heterogeneous actors - public laboratories, technical research centres, industrial firms, financial organisations, users and public authorities - which participate collectively in the development and diffusion of innovations, and which via numerous interactions organise the relationships between scientific-technical research and the market place (Callon M.et al. (1992), p. 220). The actors in these networks are not necessarily assignable to a 'pure' category of organisation or institution. 'Real' scientists can be found working for companies, users can be engineers/technologists or high-tech companies. The point is that R&D impacts are increasingly managed though this web of heterogeneous actors within the laboratory. Callon M.et al. distinguish between actors and their production on the one hand, and the organisational forms in which they operate on the other (Callon M. et al. (1992), p. 222). Focus on techno-economic networks prevents only studying dynamics within R&D organisations and, hence, missing the relationships between heterogeneous organisations which, according to the authors, are more important than the organisations themselves. For example, when explaining a laboratory's success, it is difficult not to take into consideration the relationships this laboratory has been able to form with companies, other technical centres and users. Furthermore, the concept of 'network' underlines the fact that in techno-economic configurations there is a high degree of mobility of alliances, flexibility in collaboration, and multiplicity of modes of management of the co-ordination between the actors.

The study of Callon M. et al. is in fact, one of the few examples where (techno-economic) network analysis is applied for the evaluation of the effects induced by a technological research programme of a public agency (AFME) instead of applying an input (interventions of AFME) - output analysis (Callon M. et al. (1992), p. 231). In other words, instead of considering only inputs and outputs related to the programme, Callon M. et al. followed and analysed the whole interaction chain, that is to say, the process by which inputs get transformed into outputs by following the network of actors involved in the knowledge production process.

R&D collaboration involves many and heterogeneous actors. Network typologies are, therefore, an important issue in the construction and understanding of institutional profiles. The study of von Bandemer S. et al. (1996) suggests a typology of partnerships in the European research and innovation system based on firms' view on research and innovation partnerships (interviews with structured questionnaire of 116 enterprises in twelve European Member States). This typology has in turn been applied in a study of competitiveness in networks involving vertical linkages (that is, collaboration between private companies and R&D organisations). The typology introduced in this study may be suitable for a classification of the collaboration linkages (both national and international) between firms and Norwegian technical research institutes.

4.3.5 Output variables related to new project acquisitions

One can also think of other types of institute outputs. Economic variables such as types and content of new contracts yearly, and new clients are output variables which have been used in some evaluations of R&D organisations. This information gives an indication of possible reorientations and readjustments of organisational profiles. It has been difficult, however, to find literature dealing with empirical and theoretical aspects of this type of output.

4.4 Public arenas and societal R&D outputs

In the reviewed literature there is a lack of studies on the measurement of R&D outputs in public arenas or on the societal relevance of particular research activities. Outputs across this dimension of the 'research compass' seem to be one of the most difficult to measure, yet, indicators of this kind are essential for the construction of R&D profiles for many of the Norwegian R&D institutes.

In the following we can suggest some possible information sources which could be used for the construction of some preliminary indicators in this area.

Public reports or reports submitted to public agencies are an interesting information source indicating the degree to which an R&D organisation is involved in advisory or knowledge facilitator roles. *Annual reports* could be also consulted in order to get an idea of how the concrete research projects of an R&D organisation are targeted towards public or governmental needs.

Networks and collaborations between research teams and public services are certainly indicators that could be developed in this matter. Yet, there are no databases or available information on how this communication takes place in such networks and how it functions.

When it comes to measuring societal relevance, there are a number of conceptual and methodological problems before it is possible to create good indicators in this area. As an example of a pioneering work, we can mention the study of Barend van der Meulen and Arie Rip, University of Twente on *"Assessing Societal Quality of Research in Environmental Sciences*", 1997. The aim of this study was:

> "to assess whether current practices in which societal quality is attributed to environmental research, explicitly or implicity, can be exploited to construct indications or indicators" (van der Meulen and A. Rip, 1997, p.1).

By 'societal quality' the authors mean the degree of societal relevance of a particular research activity. Four groups of indicators and indications have been identified in the study and how they can be used:

1. Outcomes of foresight studies and articulation of user needs. Is the research conducted in the proximity of those needs?

2. Other research products than scientific publications as a basis of proxy indicators of societal quality.

3. Network indicators including relations with users, other institutes, disciplinary research groups and international collaboration. Such indicators allow among other things the identification of groups which are likely to pick up the results of R&D efforts.

4. Examples can be given of real impact and use, as well as indirect use and impact by the identification of concrete organisations and agencies which endorsed the knowledge produced in the R&D activity under study.

More studies of this kind should be conducted in other societal sectors, such as, transport, health, education and in other countries before one could apply the methodological framework provided in the above-mentioned study in effective measurements of societal R&D outputs.

Conclusions

In this study we summarised the most relevant identified literature about types and measures of R&D output.

Unlike firms, R&D institutes cannot be assessed on the simple basis of market shares or profits. Unlike, academic departments, R&D institutes can also not be assessed on the simple basis of scientific production (measured as number of publications, number of citations, etc.). In fact, there is one factor representing a challenge for all modern R&D institutes, that is, balancing between research, development, other services and diffusion activities. Therefore, the criteria of success in the case of R&D institutes should be a combination of dynamism, relevance to the users, contribution to national science and technology infrastructure, value for money, independent fund-raising capability, innovative organisational approaches, effective management and solid scientific and technological outputs (Rush H. (et. al.), 1996, p. 3).

These considerations are captured in the analytical model of 'research compass' presented in Chapter 3. The four dimensions of the 'research compass' reflect the fact that research organisations produce results relevant to scientific, education, economic and public arenas. In a study of research performance of organisations, such as Norwegian research institutes, it is thus important to measure output performance across all the four output dimensions of the 'research compass'. Otherwise, one risks ignoring important contributions to areas where no measurment takes place.

The main criterion for the inclusion, or exclusion, of the studies presented particularly in Chapter 4 was their relevance to whether they provide interesting indicators for the construction of 'output profiles' of Norwegian R&D institutes. From this overview, it becomes clear that a lot of work has to be done before we can understand the production mechanisms behind the types of R&D outputs discussed above and the interrelations between these types of R&D outputs.

The dimension of the 'research compass' directed towards the production of scientific results is clearly the most well developed. Bibliometric indicators, though attached with many methodological difficulties, appear the most available and well-understood set of indicators for studying patterns of scientific R&D output. Other studies (Aksnes D., 1998; Kaloudis A., 1998) provide overviews and descriptions of such indicators. Publication activity resulting in written material other than scientific publications is, however, badly documented and poorly understood.

Across the dimension of the (socio-)economic arenas and the creation of innovation opportunities, we identified several interesting indicators. Still, a lot of work has to be done in the development of these indicators as well. We need more reliable databases and we need to understand the properties of these indicators better.

The dimension of the creation of 'embodied' knowledge where skills and competencies as well as formal knowledge (such as PhD degrees) are measured has to be developed almost entirely from the beginning. Very few studies can provide us with clues on how to begin this work. We can draw the same conclusion from the scarce studies on the R&D outputs in public arenas and on societal relevance.

As a general conclusion of this report, we can state that the measurement of the types of R&D outputs mentioned in Chapter 4 and across the four dimensions of the 'research compass' can help us to construct a good framework for measuring R&D performance. In this respect, the concept of output profiles will be helpful because:

- 'Output profiles' provide the empirical platform for understanding differences of research performance between research organisations.

and

- 'Output profiles' make it possible to understand the interrelations between various types of R&D outputs. These interrelations can thus teach us how actual research production depends on the types and missions of research organisations.

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