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Research and Technology Organisations in National Systems of Innovation

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1 Introduction[1]

Innovation is a complex phenomenon involving the production, diffusion and translation of technological knowledge into new products or new production methods. The process through which innovations emerge, does not follow a linear path (Kline / Rosenberg 1986, Edquist 1997 and 1999), it is characterised by complicated feedback mechanisms and interactive relations involving science, technology, learning, production, institutions, organisations, policy makers and demand (Edquist 1999). *National systems of innovation* (NSIs) is the most frequently used approach of the last decade for understanding the complex relations that make up the innovation process. NSIs have been analysed for different countries so that a rich sample of the variety of the participating institutions and organisations and their networks of interrelations is available (see Lundvall 1992, Nelson 1993).

Governments support the work of research organisations with the assumption that the research output put will be directly or indirectly become relevant for a country's technological performance and thus its competitiveness and growth. This assumption has been challenged arguing that (a) RTOs work too theoretically to provide useful input for companies' innovation processes, (b) the flow of knowledge from RTOs to innovating companies is scarce and inefficient, (c) the proportion of funds invested in research and output in terms of contributions to the science base of innovating firms is unfavourable. Given the drastic decrease in public resources for research support, a revision of the functions or RTOs in innovation seems to be necessary. On the other hand, the emergence of successful business service firms that offer applied research, but also technology implementation and business strategy advice to innovating companies leads to the question of an optimal division of labour between (mostly publicly supported) RTOs and (mostly private) knowledge intensive business firms (KIBS).

The present paper summarises work focused on the interaction between actors in the NSI, and specifically on the role and function of research and technology organisations (RTOs) in NSIs. By taking a functional approach to the analysis of innovation processes, it offers a new perspective on the debate on RTOs and KIBS in NISs.

A historical root of the concept of NSIs can be found in the the mid-19th century thought of List and the institutional school. In contrast with the utilitarian methodology of neo-classical theories, this school claimed more attention to the institutional and social context (Hamilton 1919). In the early 1990s the first major books surveying NSIs were published. One edited by Nelson includes case studies of fifteen NSIs divided into 'large high-income', 'smaller high-income' and 'lower-income' countries (Nelson 1993). The surveys were conducted mostly by resident researchers and they did not explicitly adopt a formal theory of 'systems', but they all made reference to the concept. The second one, edited by Lundvall, is complementary to Nelson's book, as it is more theoretically oriented (Lundvall 1992). It tries to develop an alternative to traditional neo-classical theories of innovation and has to be seen as an explicit attempt to relate the NSI approach to new theories of interactive processes of learning.

[1] The authors would like to thank Ulrich Wurzel for helpful and stimulating discussions and Mike Hales as well as Jeff Readman for useful comments.

1.1 *The concept of systems*

The literature focuses on two questions: are NSIs *systems* and how *national* are they?

The NSI perspective was adopted by many scholars in a *holistic* way (because it has the ambition to encompass all the determinants of innovation) and in an *interdisciplinary* way (because it allows to include also non-economic factors, that might help to explain innovation). However, it is not quite clear, whether it can be considered a stable theory or only a useful tool.

The notion of systems implies that innovation is embedded in a context of interacting organisations and institutions, which enhances the efficiency of innovation processes. As pointed out by Edquist (1997b), the systematic character of the NSI gives it potential for transcending the linear view of technological change, which places R&D at the beginning of a causal chain that ends in productivity growth, mediated by diffusion and innovation. The concept of 'systems' as an analytical instrument to grasp the functioning of innovation in an institutional context has been discussed by several authors. Niosi, Bellon, Saviotti and Crow (1992) understand 'systems' as sets of elements in mutual interrelation. Fleck (1992) defines a system as a set of things connected, associated or independent, so as to form a complex unity; a whole composed of parts in orderly arrangement according to the same scheme.

Innovation systems are *social* systems because they are made up with social actors (*institutions* and *organisations*, Johnson 1997). As such, they constitute sets of habits, practices and rules of social actors participating in them. Social systems are, for their nature, *dynamic* and *open* to external interaction (Lundvall 1992). This means that they can grow and be modified by the context in which they operate in an irreversible way. However, they must have a certain degree of internal coherence, which has to be higher than the degree of coherence that exists with respect to the outer world, to keep the cohesion of social systems. Further, as they are influenced in an irreversible way by the external reality, systems are *path-dependent*, which means that systems of innovation are always results of the local socio-economic history.

The use of the system concept in the context of innovations certainly lacks the analytical clearness and rigidity that *systems* theory shows (Luhmann 1984). Systems have been interpreted in a *wide* or *narrow* sense (Lundvall 1992, Freeman 1995). The former includes the whole socio-economic environment (labour markets, financial institutions, the education system etc.). The second limits NSIs to the core R&D system, composed of firms, universities and research organisations.

1.2 *National systems?*

The problem to find a sufficient degree of coherence that allows to consider them systems has been presented above. In the next step, it has to be asked, whether this coherence is bound to a national context. Niosi, Bellon, Saviotti, and Crow (1992) have outlined four elements of cohesion that are strong enough to speak of 'systems' at a national level: (1) markets and technological resources have an adequate dimension and a high degree of homogeneity; (2) there are many informal interactive interrelations among producers and between producers and customers; (3) the technical interrelations between the national industries are high; (4) the science and technology policies have usually a national base of application.

Edquist (1997) also uses a national approach, because policies and institutional set-ups are typical of nations. This allows, for example, to explain the significant differences between the NSI of two countries as close and similar as Denmark and Sweden (Edquist, Lundvall, 1993). By using the NSI concept in a wide sense, including socio-economic factors, he emphasises the national character of innovation systems.

An important critical question is, whether we can still assume geographic boundaries of the national systems or whether the process of globalisation has erased them and innovation is now a global process (see, for example, Anderson 1998). Nelson and Wright (1992), Fransman (1995) as well as Archibugi and Michie (1995) find a high degree of globalisation of R&D. As a consequence, national approaches would not make much sense. However Patel's patent analysis shows that R&D activities are to a lesser degree subject to globalisation tendencies than processes of production (Patel 1995).

Systems of innovation at levels below the national level have been studied since the beginning of the '90s, finding systemic coherence at different levels. Nelson and Rosenberg (1993) focused upon a sectoral approach, feeling that the national perspective might be too broad, because there are only a few overlaps between systems of institutions supporting different sectors. Another sectoral approach is the one of Breschi and Malerba (1997) who focused on SIS (Sectoral Innovation Systems) as a more coherent subset of NSIs, where the boundaries of the systems are endogenous, emerging from the specific context of the sector. This approach outlines the central role of private firms in an evolutionary perspective, which seems to be more influential than the role of institutions.

According to Freeman (1992) and Nelson and Rosenberg (1993) institutions have a key role in the diffusion of new technological knowledge and in supporting technical change. Institutions change due to stimuli provided by technological progress, but for their static nature they might slow down the innovation process. Lundvall (1992) indicates the institutional set up as one of the most important dimensions of the system of innovation and as one of the elements that give coherence to a national approach.

A regional perspective on systems of innovation has also been widely used, although the term 'regional system of innovation' is not common in the economic literature. Fritsch and Schwirten provide a comparative study of the interaction of institutions in three *regional innovation systems* (Fritsch/Schwirten 1999). Famous examples of local approaches are Saxenian's analysis (1994) of the *regional industrial systems* of Silicon Valley, California and Route 128, Massachusetts; analyses of industrial districts date as far back as Marshall (1920).

All these studies share the following considerations: Empirical evidence confirms that some geographic regions tend to specialise in certain technological areas (starting from Marshall 1920; Porter 1990; Archibugi and Pianta 1994; Feldman 1994; Saxenian 1994); some empirical material also shows that innovation processes are often spatially concentrated in areas that are rich of appropriate *social capital* (Breschi 1997); at a national level there are so many differences between regional rates of innovation, that regional disparities might be further aggravated by a national perspective on policies (Fagerberg 1999).

Another non-geographical approach, similar to the sectoral one, is the *technological systems* approach developed by Carlsson *et al.* (1992). In his view the boundaries of technological systems can be national, regional or international; it depends on various variables, like the size of markets and the state of technology, which boundaries exist for technological systems. In this approach, technological systems are in part consciously built by the states, while in the national system approach they are usually not consciously designed.

1.3 *From R&D to networked interaction and learning*

In the following section the role of RTOs in innovation processes and its perception and analysis in the innovation literature will be documented. Furthermore, the contribution of KIBS to National Systems of Innovation (NSI) and their relation to RTOs will be outlined as far as it has been introduced in recent discussions on innovation.

NSI concepts have emphasised the importance of systemic co-operation in innovation processes. Empirical research on NSIs has stressed the differences and functional equivalents between countries in the organisational configuration of NSI and its impact on a country's economic performance (Nelson 1993, Lundvall 1992, Harding 1995, Sweeney 1996).

Along with the discovery of the systemic nature of innovation, non-linearity of processes has been identified as a realistic concept of innovation (Kline / Rosenberg 1986). This non-linearity directs attention to the interaction of organisations in NSI, since it involves communication and feedback which would not be necessary in a simple chain from research to new products. Under the heading 'Interactive creation of innovation', Sweeney gives the following description:

> Innovation ... is an outcome of new knowledge and information created and integrated through networks of people, who have core competence in a sectoral product and product engineering technology or discipline, interacting with people of other disciplines and functional know-how. (Sweeney 1996, p.17).

Whereas the early literature on NSI focuses on the complementary character of research institutions and innovating companies and the systemic characteristics of competitiveness (Nelson and Rosenberg 1992, Freeman 1987, Porter 1990), later elaborations stress the importance of learning (Lundvall 1992). The focus on learning widens the perspective to include other than technological factors, such as organisational change, human capital formation and marketing issues, and directs attention to new actors that facilitate learning. The fundamental difference between approaches based on R&D expenditure as the main indicator for innovativeness and approaches based on a system concept of innovation is the shift of attention from *the production of technology* to mechanisms that enable firms to *use technology to innovate and to enhance their competence*. The combination of knowledge about new technologies with existing competencies in technical, organisational and strategic matters thus creates new opportunities for innovation (Sweeney 1996). Learning is also a vital concept for the NSI itself. Actors in the system do not only have to learn to use the output and facilities of the system, but also to develop the skills to change the system according to changing economic, political and technological challenges (Hollingsworth 1998, Edquist 1999).

The relevance of organisations and institutions that support innovation in the economy, their roles and their status in the division of labour in research systems have been widely discussed (see, for example, Nelson 1988, Nelson and Rosenberg 1994, Acs, Audretsch, Feldman 1992). Recent studies suggest that the roles of organisations and institutions, their division of labour as well as their patterns of interaction are changing along with new research and technology policies and new economic requirements at the firm and industry levels.

2 Definitions and categories

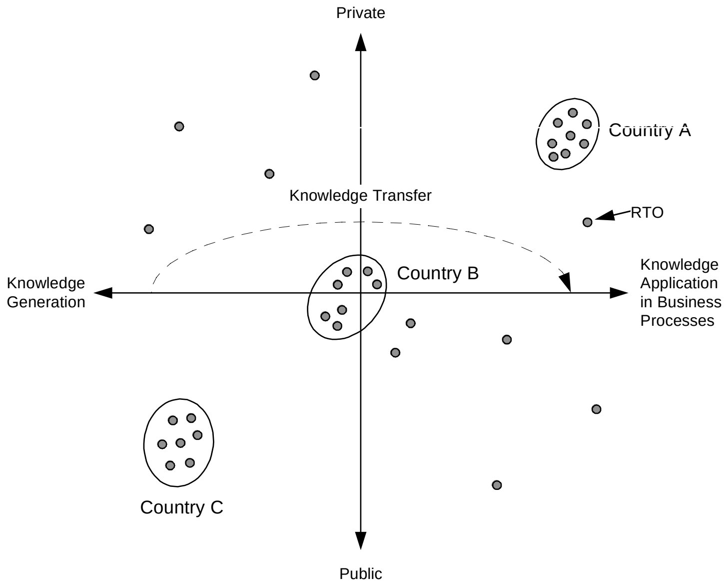
2.1 *Research and technology organisations (RTOs)*

Attempts to define 'RTOs' do not lead to satisfactory results because of the large variety of institutes and organisations, their purposes and configuration across countries. Whereas in some cases, the main contributors to the national technological knowledge base are universities, in others they are technology-specific or industry-specific research institutes. Some of them are public or semi-public, others private and/or subsidised through government funds. In a number of countries RTOs are mainly technology-oriented, in others they also cover research on education, the social system, markets or management issues. The range of tasks goes from predominantly basic research to technology transfer or applied research and even to implementation support. As a consequence, some authors emphasise the public or semi-public character of RTOs (for example, Fritsch/Schwirten 1999), while for others the distinctive feature is the role in technology transfer (AIRTO Review 1998-99, cited in Hales 1999a). In some publications authors have mainly universities in mind when writing about institutions contributing to the NSI (Heitor/Conceiçao 1999, Nelson 1986, Mansfield 1995, Mansfield 1991, Nelson/Rosenberg 1994), which obviously makes sense for the countries they take their evidence from. In some countries the research performed in RTOs typically takes place mainly in university institutes or in institutes that organisationally belong to universities. In addition, a large part of the literature on the contribution of RTOs to innovation, on the question of basic vs. applied research and on the science/technology dichotomy refer explicitly to activities conducted in universities. In the present context a *wide* notion of RTOs will be used which includes universities, whereas RTOs in the *narrow* sense refer to organisations outside universities. Given this heterogeneity, typologies or classifications seem to be more helpful than definitions (EIMS 1995).

Ongoing changes in the organisational structures, judicial frameworks and funding bases for RTOs in many countries further contribute to a diversification rather than a harmonisation of the picture. 0 shows the positions of RTOs along two axes: a public-private axis and a knowledge generation (basic research) - knowledge application (applied research/consultancy) axis.

If RTOs are positioned according to the degree to which they might be considered public or private and according to their role on the knowledge generation, knowledge transfer, knowledge application axis, cluster analysis (in the statistical sense) might allow to identify country specific agglomerations. In 0, for example, in country A there is a strong presence of private RTOs specialised in the application of knowledge in business processes, whereas country B hosts a lot of RTOs of the semi-public type, concerned with knowledge transfer. This picture could look quite different in a few years time, if RTOs move more towards applied research or cannot rely on the same share of public funds as at present.

Figure 1 RTOs in national systems of innovation



Source: DIW 1999

2.2 *Knowledge intensive business services (KIBS) and RTOs*

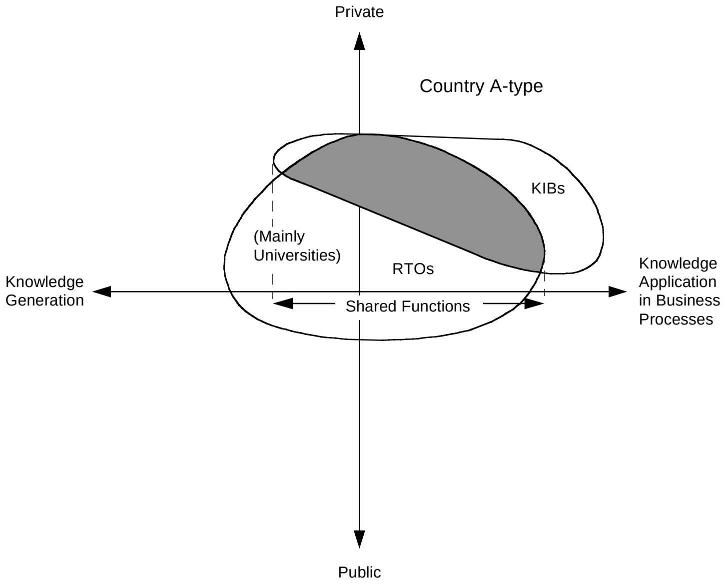
This leaves us with the task to distinguish RTOs from KIBS (or knowledge-intensive business services). The notion of KIBS refers to Bilderbeek / den Hertog 1998 and to Miles / Kastrinos et al. 1994. Bilderbeek / den Hertog define KIBS as

- Private companies or organisations
- Relying heavily on professional knowledge i.e. knowledge or expertise related to a specific (technical) discipline or (technical) functional domain, and
- Supplying intermediate products and services that are knowledge-based.

The emphasis here is on the private nature of KIBS as market-related service providers and on their relative closeness to the innovating firms and thus to applied research. In some countries where RTOs have been privatised to a large extent, the only feature which distinguishes them from KIBS seems to be their history. This means, there is a considerable overlap between the two types of organisations in terms of their positioning on the private / public and the knowledge generation / knowledge application axes. This means that there are services supporting the innovation process (or service functions) which are provided by both types of organisation.

Figure 2__ Innovation-related service providers - RTOs & KIBS

Type A



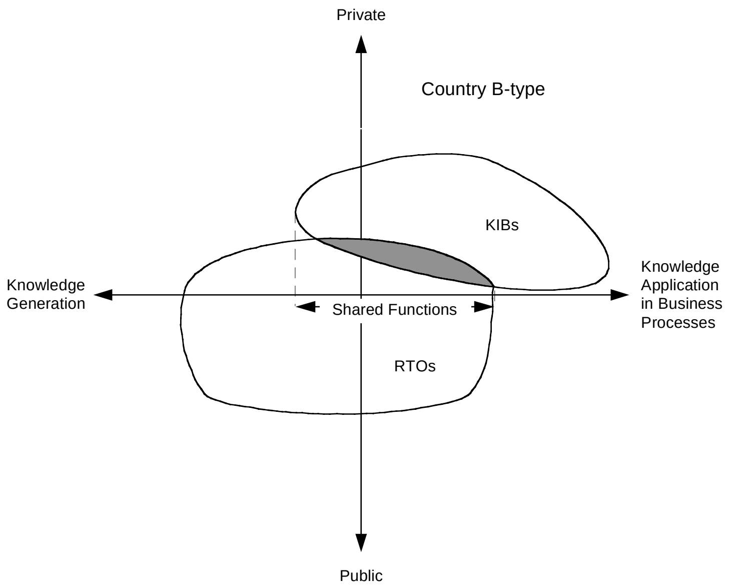
Source: DIW 1999

Figure 2 and Figure 3 show the location of KIBS and RTOs in two types of countries. In the country A- type of innovation systems (Figure 2) RTOs do not differ much from KIBS and thus share a wide range of functions with them, although they might operate from a different institutional background. A second feature of country A-type RTOs (in the narrow sense) is that they do hardly any basic research. The part of *knowledge generation* which is attributed to RTOs here mainly refers to basic research conducted in universities (and i.e., in RTOs in the wide sense). The country B- type setting (0) shows less overlap and a somewhat larger share of RTOs engaging in basic research, whereas applied research shows a strong presence of KIBS. The public funding for RTOs still plays a significant role in this type of NSI and is a feature which sets RTOs apart from KIBS. Here the shared functions cover a much smaller field of activities. In both cases, it depends on industry and firm-specific features on the user side and on the availability of services on the supply side whether KIBS or RTOs are delivering the service within the range of overlapping capabilities. There is also evidence for increasing competition between RTOs and KIBS in some service functions.

Figure 2 and Figure 3 illustrate the spectrum along which RTOs and KIBS are variously situated. A longitudinal analysis might reveal a movement in one direction of the axis or towards one quadrant and thus document a shift from RTOs to KIBS in some countries. However, these movements can be country-specific and they do not necessarily have to be irreversible. According to the functions which dominate and to the funding situation in particular years, there might be KIBS which look more like RTOs for a certain period of time and then go back to be genuine KIBS. The exact allocation of an organisation might still remain somewhat arbitrary, depending on the self-assessment of the actors and on the history of the NSI.

Figure 3__ Innovation-related service providers - RTOs & KIBS

Type B



Source: DIW 1999

The function of KIBS in NSIs has only recently become an issue in innovation research. Two lines of thought lead to the inclusion of KIBS in NSI concepts: the privatisation of formerly public research institutions on the one hand, and a new configuration of manufacturing-service relationships in recent analyses of the knowledge-based service economy on the other (Hauknes 1996 and 1998, Bilderbeek / den Hertog , Strambach 1997). The increasing interest in services as part of the innovation system is not independent from the general shift from neo-classical to evolutionary models. Acknowledging that information does not equal knowledge and that there are significant diverse functions of explicit and tacit knowledge, directs attention to those institutions which can enhance the productive exploitation of knowledge and competencies that cannot be bought off-the-shelf in the form of immediately applicable new technologies (Sharp 1999). KIBS have been introduced as organisations which can constitute a *second knowledge infrastructure* to complement the existing knowledge infrastructures which consist of public and semi-public research institutions (Hauknes 1998, Bilderbeek / den Hertog 1998). Without describing them as KIBS, Bessant and Rush provide a study of the role in the innovation process of consultants of numerous kinds. They document the variety of functions, and the central role of this kind of service for innovation, particularly as agents of government innovation policy (Bessant/Rush 1995).

Although little attention has been given to the contribution of private service firms in innovation, it can be assumed that highly differentiated and highly sophisticated service requirements will have to be met in future innovation processes. Thus, studying the emergence of KIBS and their interaction with RTOs on the one hand and with innovating firms on the other should become a major concern of future innovation research (see also Antonelli 1998).

2.3 *The classification of RTOs - Institutions and functions*

It is difficult to precisely define what an RTO is, and identify which organisations are to be included and whether any definition could be valid over a reasonable stretch of time. These difficulties have been acknowledged by researchers trying to monitor innovation at the European level (EIMS 1995, p.i). Given these obstacles it seems appropriate to refrain from an abstract definition which would always overemphasise the situation in one country and could thus not do justice to configurations of the NSI in other countries. However, typologies and classifications of RTOs seem to be quite useful tools to grasp the phenomenon. All classifications run the risk of not taking sufficient account of 'mixed' institutes which, for example do basic research whose output is directed towards academic journals as well as applied research for private companies. In these cases the attribution of institutes to classes can change easily according to actual focuses. Among the many proposals for RTO classifications, a basic categorisation emerges which allows for further differentiation: RTOs can be classified according to (see also Miege in EIMS 1995, p.3 and Hales 1999b):

- The customers they mainly direct their output to (single sector or multi-sector, policy makers, industry, national or international users, scientific community)
- The technologies or range of knowledge covered (single technology or several technologies, single discipline or multidisciplinary)
- The contractual basis of projects and governance of the supplier/client interaction (loose or strict specification by customers, short-term, long-term)
- Their funding (market sources, public sources, core-funding, contract based)
- The intensity of competition ('protected' national quasi-monopolies vs. market oriented organisations)
- The functions in the innovation process that they provide.

Other classifications lie across these categories. For example, in order to distinguish research conducted in private enterprises from that conducted in other institutions, the term *public sector research* has been used (Faulkner/Senker 1994). In the above categories this distinction would be covered by the *funding* criterion as well as by the *contractual basis/governance* criterion.

Some authors speak of *academic research* to draw the line between (private) companies and (mostly public) research institutes (Mansfield 1991). Academic research is a category comprising those parts of universities that are dedicated to research and those parts of other research institutes that do academic work as distinct from consultancy. A different category - *contract research organisations* - has been introduced in the context of OECD studies, for the research institutes among the RTOs in order to distinguish semi-public institutes that do not only engage in basic, but also in applied research from university researchers (Webster 1994). Whereas the academic/non-academic distinction mainly refers to the direction of outputs, the contract research criterion points at a funding or an intensity of competition categorisation.

The first five criteria in the list above can be considered rather traditional. They imply that it is possible to identify organisations which can be categorised according to institutional considerations. The final 'functional' distinction offers possibilities to go beyond institutional criteria and thus to grasp changes in NSIs which happen within and between organisations.

Over the past ten years RTOs have changed in many countries. Partly this was due to deregulation policies of national governments that resulted in either privatisation of RTOs, in overall cuts in funding or in a shift from general research funding to contract- (or project-) based models. Partly these shifts are a consequence of changing requirements in industry which put more emphasis on knowledge (instead of technology), on technology transfer, on the application and integration of technology in existing scenarios and thus on management consulting or training activities. Enabling firms to learn rather than delivering packages of ready-to-use technology (Lundvall 1999, Sharp 1999) has become the central concern in scenarios with rapid innovation cycles. RTOs had to respond to this shift in demand.

2.4 *Institutional and function-based characterisations*

As a consequence of these changes the institutional diversity of RTOs and their changing task profiles make traditional *institutional* definitions of RTOs unsuitable for the purpose of understanding their role in national innovation systems on the background of a globalising learning economy. However, *functional* approaches can help to more adequately analyse and compare RTOs and their relationship with customers, private innovation-related service providers and the policy system. Furthermore, analysing the role of RTOs and their contribution to NSIs in terms of functions they assume in the innovation process also allows to identify their relationship with KIBS which assume overlapping or different functions.

A comprehensive list of service functions in innovation has been provided by Dodgson and Bessant. They distinguish the following functions (Dodgson / Bessant 1996, see also Hales 1999b):

- Recognising needs for innovation
- Aligning technology strategy with business strategy
- Integrating and combining inputs
- Exploring the range of technological options; searching for good fit with needs
- Comparing and ranking options
- Selecting options
- Acquiring technology
- Implementing technology
- Using technology, developing skills for best use
- Learning and continuous improvement, embedding in routines.

This list reflects the state-of-the-art of research on innovation and takes into account the diversity of needs occurring in the innovating firm. At this stage, there is no given division of labour between actors, and all functions can be either attributed to the innovator, to RTOs, to KIBS or to suppliers and even customers of the innovating firm.

Bessant and Rush emphasise the technology transfer functions in an analysis of consultants as 'bridging institutions' (Bessant/Rush 1995). Quite similar to Dodgson and Bessant, however in a narrow focus, they identify several stages of technology transfer ranging from the recognition of opportunities, through search, comparison and selection, acquisition and implementation to long-term use. The latter includes learning and development. (Bessant and Rush 1995, p.98). Although Bessant and Rush are quite explicit in the analysis of the functions consultants ought to play in innovation, they remain much more open with respect to the identification of the actors. Bridging *the management gap* as a central function to be fulfilled hints at the management consulting profession as the main actors. Later in their paper examples are given (technology brokers, university liaison departments, regional technology centres, innovation agencies and cross-national networks) which seem to point rather towards what traditionally could be seen as RTOs. In this sense, the analysis can be seen as an illustrative example of the blurring boundaries between RTOs and KIBS and the irrelevance of institutional attributions for a functional analysis. The strength of this approach is that it sees the technology transfer process as based on interaction between producer, transfer agents and users and is thus able to include informal and tacit knowledge as an important component of innovation.

More technically oriented functional categories are given by authors who underline the basic vs. applied research distinction, the role of prototyping functions (like testing, standardisation, design and certification) and diffusion (eg. Rush et al 1996; AIRTO 1999). Hales (1997) offers a graphical representation of the functions referred to in the Rush et al study of major European and Far East research and technology institutes. It takes the form of a 'technology lifecycle model' of innovation-related service functions and consists of three triads of broad functions: *originating, configuring and operating* . The first 'upstream' triad includes functions of basic research, applied research and the development of standards, tools and metrics. The mid-stream category of 'configuring' comprises positioning and resourcing of new technologies, design and applications development and technical services. Finally the downstream 'operating' triad contains the functions of technology deployment, operational services and productive use. The model is shown in 0. The service functions classified under this schema (forty are identified on the basis of Rush et al's data) covers a wide range of activities which may contribute to innovation processes in a complex set of interaction between different actors.

The analysis of innovation in terms of service functions seems to promise new insights into the mechanisms of interaction in NSI. However, an empirical test of the validity of the concept is still missing.[2] The relative importance of these service functions as well as the institutional and procedural division of labour between sets of actors still needs to be investigated. Fritsch, Bröskamp and Schwirten (1997, p.23) offer a rudimentary form of functional analysis in their study of public research and innovation in Saxony. They distinguish between the analysis of framework conditions, the generation of new ideas, the development of prototypes, and the implementation of existing ideas.

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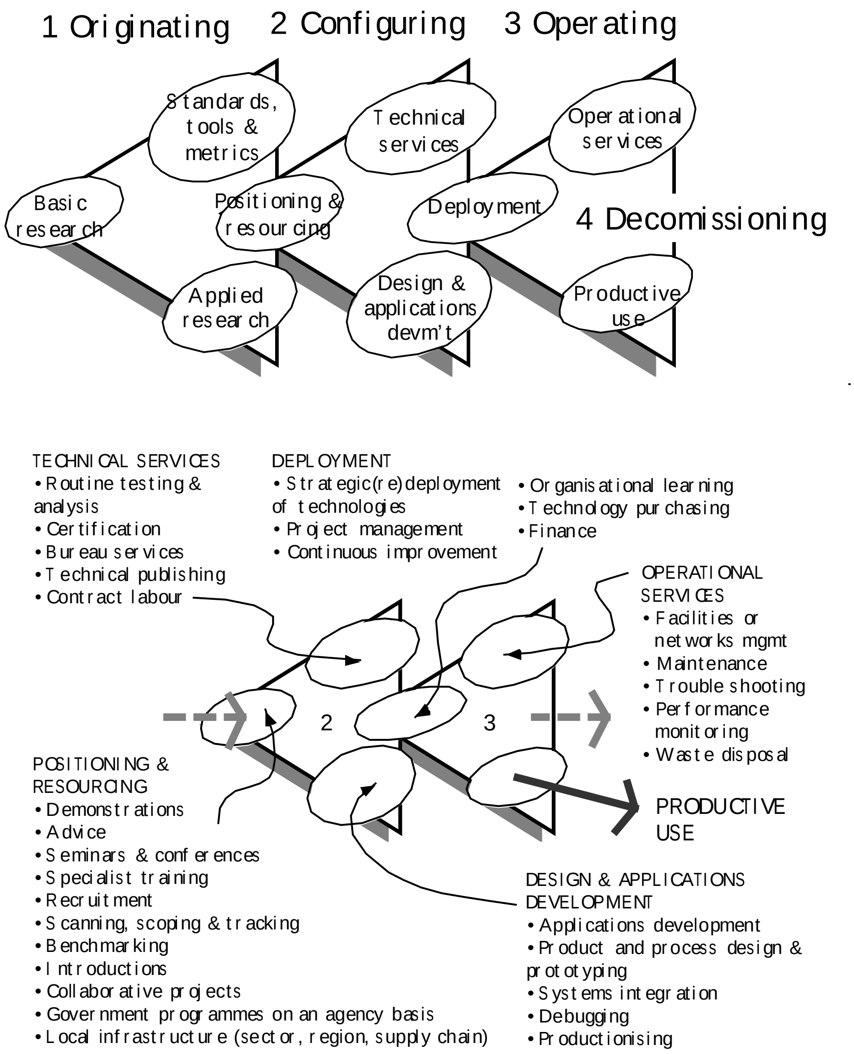
[2] This gap is supposed to be filled by a research project conducted within the European Commission´s TSER programme: RISE (Research and Technology Organisations in the Service Economy).

Figure 4__ Functions in the technology lifecycle as performed by research and technology institutes - Three triads



Source: Hales 1997. Based on data in Rush et al 1996.

3 Research and technology organisations in national innovation systems

In the literature there are different perspectives from which RTOs are analysed. One strand of research deals with the *justification of public support* of RTOs; another focuses on their *functions* in innovation and *flows of knowledge* from these organisations to other parts of the innovation system and (most importantly) to innovating firms, and a third is concerned with systemic processes of *learning* and the role of RTOs in institutional learning. The second strand includes debates about the usefulness of basic research, assuming that what is done in universities and RTOs is mainly basic research. The following text will be organised around these literature clusters and research paths, although a considerable overlap seems to be unavoidable.

This translates into four questions to which sometimes contradictory answers have been presented in the literature:

- Should basic research conducted in RTOs be publicly funded or subsidised ?
- What is the function of RTOs in innovation systems ?
- How efficient is the transfer of knowledge from the area of public / basic research to innovating companies ?
- Does the existing innovation system adequately support learning processes in innovation ?

3.1 *Public funds for RTOs?*

The fact that most countries show a variety of organisations conducting basic and/or applied R&D which are completely or partly financed by public funds has been explained with arguments that to a large extent refer to Nelson 1959 and Arrow 1962. The following arguments are repeatedly stated as rationale for public or state intervention in the generation of basic research (Dosi 1988, Pavitt 1991, Brooks 1994, Senker 1991, Faulkner and Senker 1994, Nelson 1996, more controversial Dasgupta/David 1994, Edquist 1999):

- The public good character of R&D and knowledge is being stressed as a reason for a lack of incentives to engage in private R&D.
- One of the main conclusions from the first argument is that competitive regimes produce less basic research than desirable for the economy as a whole.
- Private investors tend to be risk adverse and hence would not invest in major technological advancements with an insecure outcome.
- Companies' profit orientation leads to short-term innovation policies and neglects the long-term benefits of complex research programmes.
- Benefits from basic research are difficult to appropriate.
- Basic research shows economies of scale which would remain unexploited, if the research were carried out by individual firms.
- Most small and medium-sized firms could not afford large R&D departments and are therefore not able to provide the technological basis for their innovation activities.

- Basic research in publicly financed institutions has spillover effects that stimulate research in private companies.
- The results of basic research should be available to the general public in order to guarantee the rapid diffusion of new technologies and thus to enhance technical progress in all industries concerned.
- Secrecy in knowledge production due to private appropriation of research results hinders technology diffusion and the modernisation of the economy.

Hence government funding seems to play a vital role for economic and technological development. Edquist stresses the superiority of markets in economic activities and points out that (1) markets have to have failed and (2) the state has to have the ability to solve the resulting problems to justify state intervention. The advantages of public actors in this context are: (a) the state may use non-market mechanisms, and (b) state actions can improve the functioning of markets or create new markets (Edquist 1999). Metcalfe discusses the phenomenon of missing links between science and technology in Europe which have led to a situation in which excellent results in the production of knowledge in science are not matched with an equally high performance in technology production (Metcalfe 1998). However, he warns policy makers of relying too strongly on the support of technology and innovation in the firm thus neglecting science and knowledge creation. Adoption of technology in his view bears the risk of high losses through costly trial-and-error processes.

There are various ways in which government can subsidise research in public and private organisations (Dasgupta / David 1994, Heitor / Conceiçao 1999).

The empirical validity of arguments for public research funding has been tested in several contexts (Nelson 1986, Acs et al. 1992, Mansfield 1991, Mansfield 1995, Senker 1991, Faulkner / Senker 1994, Pavitt 1991, Nelson / Rosenberg 1994, Beise / Stahl 1998). The general result of all studies was that basic research conducted in RTOs did have positive effects on companies' innovativeness and that thus public funding was justified. However, the studies differ with respect to the most important features of basic research from which private firms could benefit and with respect to efficient channels of knowledge transfer. Beise / Stahl (using the same method as Mansfield 1991) conclude that only a certain type of RTO (Fraunhofer Institutes) have a significant impact on company performance (Beise / Stahl 1998). Therefore other institutes should not be publicly subsidised any longer.

As Metcalfe (1998) states, the market failure approach is very weak, because it attempts to establish a policy perspective within the confines of the neo-classical static equilibrium theory of markets and industry. Already in 1991, Pavitt argued that public subsidy cannot be justified only by the inappropriability argument and finds a stronger point (referring to Nelson 1959) in the uncertainty argument. He adds a further argument in stressing the political necessity to attract R&D activities of large firms to the national market in a globalising economy. However, the most important reason for public spending is the training in research skills which happens in public RTOs. For private firms the incentive to engage in training is small, because they will not benefit from it when researchers move on to another company. For Canada, Hanel and Palda also deny inappropriability and claim increased attention for the effectiveness of government spending in innovation support (Hanel / Palda 1992). Although Pavitt acknowledges the significance of studies that try to prove the economic value of basic research (such as Mansfield 1991 or Beise/Stahl 1998), he also argues that they might miss the point, and refers to David et al. who claim an '... alternative conceptualisation' which 'focuses on basic research as a process of learning about the physical world that can better inform the processes of applied research and development' (David et al. 1988).

The question of what RTOs should look like to best serve innovation processes, evolves along several debates: about the most effective share of government funding, about their research agenda, about a demand-pull or a technology-push dichotomy, about the best way to make them co-operate with industry. Pavitt raised a number of additional issues that seem to be crucial to identify the factors determining efficiency of RTOs (Pavitt 1991): He asks, if 'large and productive institutions are good because they are big, or big because they are good?'. Size can indeed be an important factor, if economies of scale prevail or if interdisciplinary research provides synergy effects. Pavitt continues with the role of accumulated scientific and managerial skills. This is a major concern in recent debates about the 'right' extent of turnover of personnel in RTOs: building on existing expertise is an important factor, but so is the continuous input of new ideas. Civil service-type employment for researchers might not be an appropriate solution, but neither is a completely project-based short-term hire-and-fire strategy (PBBL 1997).

With respect to the appropriate organisational unit, Pavitt (referring to Platt 1988) concludes that not whole universities, but closely related subjects seem to provide the best results. Larédo and Mustar (1999a; 1999b) also emphasise the issue of the appropriate unit of analysis in institutional studies. They propose 'the lab' as the unit in studies of the production of basic and applied research, rather than the whole organisation (university, institute, etc).

3.2 *The division of labour between RTOs and other NSI actors*

The institutional diversity of RTOs is as complex as the range of activities they engage in. Thus, a simple attribution of basic or applied research to types of institutions runs the same risk of over-generalising special cases as an abstract definition of RTOs. Authors for whom RTOs are more or less identical with university institutes tend to argue that RTOs specialise in basic research (this view is particularly common in the US, see Nelson 1986, Mansfield 1991, Acs, et al. 1992). In Germany RTOs range from institutes explicitly founded to engage in basic research (like Max-Planck Institutes), those with the specific purpose to do basic research, but with a strong focus on later applications in industry (Helmholtz Society), to those with a clear linking function and the mission to assist firms by providing applied research which can be directly used to solve problems on the shop floor (e.g., the Fraunhofer Society or the Rationalisierungskuratorium der deutschen Wirtschaft, RKW). Thus, in some innovation systems the division of labour between institutes engaging in basic research and those doing applied research is more clear-cut than in others. Whereas some RTOs have the explicit purpose to bridge research and development activities, others, like university institutes, serve the more general goal of increasing knowledge, and the transfer of this knowledge into the economy is left to a set of mechanisms that again can be country-specific.

Senker (referring to the UK research councils) introduces *strategic research* to describe a type of research which is dedicated to a strategic (innovation) aim without directly supporting an innovation project. It is thus more target oriented than basic research and more general than applied research (Senker 1991). It seems that the science/technology dichotomy is used by some authors (Brooks 1994, Nelson/ Rosenberg 1993, Pavitt 1991, Metcalfe 1998) as a synonym for basic/applied as well as for the research/development dichotomy. In the context of discussions about the relationship between science and technology, Pavitt explains his view of the complementary character of basic research and development activities:

> [B]asic research seeks generalisations based on a restricted number of variables, and results in publications and reproducible experiments. In business, a combination of research and (more important) development, testing, production engineering and operating experience accumulates knowledge on the many critical operating variables of an artefact, and result in knowledge that is not only specific, but partly tacit (uncodifiable) and therefore difficult and costly to reproduce. (Pavitt 1991, p.111)

In general, different types of research (basic, applied, scientific, technological, academic, business oriented) are being attributed to different institutions (for example in Dasgupta/David 1994). However, with an increasing need to justify their usefulness for companies' competitiveness, research institutions seem to engage in applied research to a larger extent. Outsourcing tendencies lead to the contracting out of applied research and/or development functions to research institutes or specialised firms (KIBS). One of the specific advantages of some RTOs in Germany seems to be the combination of basic and applied research which allows them to combine two neighbouring types of expertise and to realise synergy effects from mutual feedback between the two areas. Brooks emphasises the importance of knowledge flows in both directions, from science to technology and vice versa (Brooks 1994). He identifies the ways in which science contributes to the development of technology and how technology enhances science. Other scholars tried to measure these flows with econometric models (Kline, 1990) or with more pragmatic methods (Kash and Rycroft, 1994). Furthermore, it could be argued that at least large private companies can draw advantage from engaging in basic research, because this will enable them to implement research results from external sources more efficiently.

4 Learning and channels of knowledge transfer

4.1 *Knowledge and channels of knowledge transfer*

Understanding the functioning of NSIs and of the interaction of their main institutions requires to understand the basic features of knowledge. In a *neo-classical* view, firms interact in order to share the risks connected to the production of technological knowledge. These risks are due to the specific attributes of knowledge. According to Arrow, knowledge has the same nature as information, and as such it bears three problems that give rise to market failure: it is a public good, because it is not possible to create a market for knowledge, since the producer cannot appropriate it; the process of creation of knowledge is dominated by uncertainty, outputs are not predictable by inputs; and there are economies of scale in the production of knowledge.

This view has been challenged by authors who deny the inappropriability argument (Pavitt 1991, Metcalfe 1998). A new way of thinking about knowledge and the generation of innovations has been established in Nelson and Winter’s *evolutionary* model. Here a new concept of knowledge that differs from ’information’ is used in order to avoid problems related to public goods (Nelson / Winter 1982). A basic difference between the neo-classical and evolutionary approaches is the recognition that a large share of knowledge is tacit (Polanyi 1958 / 78, Lundvall 1997). This means, it is embodied in the scientist and it is not tradable, because it has not been translated in a codex. If this is true, it is obvious that this type of knowledge does not incur problems of property rights.

Nelson and Romer (1996) established a taxonomy which distinguishes *hardware,* which includes physical goods, natural resources, energy and physical infrastructure, from *knowledge.* Further on, Foray and Lundvall (1996) distinguish two kinds of knowledge:

- *Software (or ideas,* as in Conceiçao and Heitor 1999): knowledge which is codified and stored outside the human brain, and
- *Wetware (or skills,* as in Conceiçao and Heitor 1999*)*: knowledge that cannot be dissociated from an individual, because it is stored in the brain of human beings and comprises convictions, abilities, talents, etc.

The conceptual difference between software and wetware lies in the level of codification, while ideas can be articulated in words or other means of expression, skills cannot be formalised. The codification of knowledge is possible only for ideas, were it takes the form of a process of reduction and translation in a standard and compact format, that reduces the costs of storage, transmission and reproduction (David and Foray 1995). Codified knowledge can be transferred over long distances and across national boundaries with low costs (Foray and Lundvall, 1996), (the same as information) and without the permission of the author. Ideas can thus be used by any number of people simultaneously, and the cost of their distribution is usually lower than the cost of production. On the other hand skills are rival in use, and their distribution, whenever possible, is slow and expensive. This explains, why science-based firms and science organisations collaborate in order to share knowledge and particularly skills.

The second kind of knowledge, known also as *tacit*, consists of highly specific pieces of technological know-how acquired with long processes of learning. As a consequence it is specific of the full set of environmental and social factors that shape the learning process (Antonelli 1999). In contrast to codified knowledge, tacit knowledge (skills) cannot be easily transferred, because it hasn’t been stated in an explicit form. According to Polanyi it can’t be sold and bought: the only way to transfer it, is through a specific kind of social interaction similar to apprentice relationships (Polanyi 1958 / 78).

The development of information and communication technologies helped the process of codification of knowledge in standard form and allowed to transfer knowledge over long distances at a substantially reduced cost. It thus was a prerequisite for an intensification of the exchange of codified knowledge. Antonelli (1999) stresses the growing importance of transactions of codified knowledge among firms, or between innovating firms and knowledge-intensive business firms (KIBS) specialised in the generation of technological knowledge to be delivered and sold to third parties. The external acquisition of disembodied technological knowledge is becoming an important way to increase the total amount of knowledge that a national system owns.

Given the natural persistence of a tacit share of knowledge and the speed of innovation and globalisation processes, Lundvall and Borràs (1997) outline the importance of learning as a key factor of development for national economies. It is more important to be able to acquire new skills rather than to possess a stock of knowledge. The system's capacity to learn is a crucial factor of competitiveness. As a consequence, Lundvall (1997) defines *learning economies* as fundamentally different from *knowledge-based economies.*

If there is a division of labour between RTOs and innovating companies such that basic (and strategic or applied) research is conducted in RTOs and the development of new production methods and products takes place in the companies, the channels through which the knowledge created in RTOs and needed in companies are of crucial importance for the performance of NSI. RTOs have been accused of focusing on their own research agenda in an ivory tower perspective without realising the applying industries' interests (Fritsch / Schwirten 1999). A particular German characteristic of the university system is that until the early eighties collaboration with industry was considered quite problematic in terms of scientific independence in most academic circles. This has only changed over the last few years, and good contacts with industry seem to contribute to a university's reputation nowadays (Schmoch 1998). However, the historically established distance still has an effect on the intensity of collaboration between industry and academia in Germany.

The often expressed concern about the isolation of RTOs and their inadequacy for the practical purposes of the innovating company hints at less than optimal transfer mechanisms of knowledge from RTOs to firms and of research requirements from firms to RTOs. The increasing concern about network building as a prerequisite for outstanding technological performance, reflects the role of interaction between firms, but also between firms and RTOs. In some countries RTOs themselves have the distinct purpose of technology transfer (Abramson et al. 1997). The combination of government funding with contract research which characterises RTOs in some countries, seems to offer a good framework for transfer purposes: expertise gained in basic (publicly funded) research combines with knowledge accumulated in contract research with industrial clients.

A paper by Margaret Sharp which sums up innovation policy conclusions from the fourth TSER framework programme, emphasises the importance of bridging the industry-academic gap (Sharp 1999). Lundvall (among others) sees communication between actors in the NSI as an undeniable element of the learning economy and claims efficient mechanisms of *knowledge sharing* (Lundvall 1999).

There is consensus about the fact that more than one channel of knowledge transfer exists and that it cannot be said generally which channel is more important than others. Industries, but also countries (due to different operating rules for RTOs and different company cultures) and firms of different size have developed their own patterns of exchange of knowledge. The communication between agents of different research traditions and from different organisations, and thus the transfer of knowledge can be difficult, because they do not share the same research cultures (Dasgupta / David 1994). Furthermore, informational asymmetries impede the exact formulation of requirements and contracts by the parties involved. This is especially problematic in the case of tacit knowledge (Dasgupta / David 1994). Chapter 7 below discusses the 'channel' issue in terms of the 'presentation' of a service product in the delivery of a knowledge-intensive service, with particular attention to tacit knowledge and embodiment in human and non-human forms.

Beise and Stahl distinguish three channels of knowledge transfer: education, research and consultancy (Beise / Stahl 1998). Faulkner and Senker use three main forms of interaction: literature, contacts and recruitment (Faulkner / Senker 1994). In a more differentiated perspective these can be further broken down into (see also Fritsch, Bröskamp, Schwirten 1997):

- Transfer / exchange of personnel
- Informal exchange of information
- Consultancy
- Contract research
- Formal co-operation in research projects
- Common use of equipment
- Training courses
- Publications
- Conferences

Some of these channels are formal, some informal. Some lead to knowledge appropriation, some keep access to knowledge in the public sphere (or semi-public) sphere. (Conferences with high fees and publications at high prices constitute an increasingly common exclusion mechanism. Knowledge distributed via these channels cannot be called 'public' any longer). Generally, knowledge transfer seems to be the more difficult, the more context dependent the specific bundles of knowledge are (Arora / Gambardella 1994). Fritsch, Bröskamp and Schwirten found in their study on the role of RTOs in the Saxonian innovation system that informal exchange of information, consultancy and contract research were the main transfer channels, whereas training activities and the transfer of personnel were the least important categories (Fritsch, Bröskamp, Schwirten 1997, p.21). Schmoch emphasises the importance of collaborative research and informal contacts in a comparison of university-industry interaction in the US and in Germany (Schmoch 1998).

A particularly effective form of knowledge transfer has been attributed to regional research clusters. Science parks and, more generally, proximity between organisations were supposed to cause regional spillover effects (Mansfield 1995, Fritsch / Schwirten 1999). Whereas many science parks did not produce the desired effects, regional proximity seems to have an impact on the intensity of interaction (Fritsch / Schwirten 1999). Beise and Stahl cite more controversial results even on the latter point. Although geographic proximity constitutes an advantage for successful linkage between RTOs and private firms, co-operation among RTOs and other academic research institutes tends to be non-local (Fritsch / Schwirten 1999). However, recent evidence also seems to suggest that common research projects of (even distant) partners in industry and academics show better learning effects than institutions like science parks (Sharp 1999). Schmoch points out that in the US interaction between industry and the university system tends to be concentrated in new research-intensive areas, whereas in Germany it is most intensive in technologically mature areas (Schmoch 1998).

Several indicators of the intensity of knowledge transfer between RTOs and companies have been used. Mansfield (and based on his study also Beise and Stahl) have asked companies to indicate, whether they have conducted innovations which could not have been realised without the existence of (recent) public research (Mansfield 1991, Beise / Stahl 1998). Other authors approximate patterns of co-operation and the configuration of research networks by analysing co-authored publications (for example, Penan 1996, Hicks / Isard / Martin 1996, McCain 1986).

Faulkner / Senker have provided a set of factors which determine the mode and intensity of interaction between RTOs and innovating companies. They distinguish factors attributable to *industry sectors, to public sector research, to technology and to the individual firm*. At the industry level, the relevant variables are: the character of the new product development and the size of the firms. Public sector research factors are: the availability of expertise in the RTO, public policy context and the role of the RTO as a key user. On the technology side the general character of the technology and age and dynamism of the field have been identified as relevant factors. Finally, at the firm level, the existing knowledge base and the propensity to linkage determine interaction (Faulkner / Senker 1994, p.693).

4.2 *Interaction and learning*

Learning is an activity which takes place in every part of the economy, also in traditional industries. Here, the technological opportunities may be lower, but in all industries there will be niches where the potential for learning is high. In Lundvall's model firms are exposed to transformation pressure, like technological changes and changes of competition or of governance regimes. The firms that have a strong knowledge base and that have learnt to learn, can adapt to changes and gain competitiveness. The way firms adapt is still under discussion: according to Lundvall (1997) some systems may adapt through flexible labour markets, others through functional flexibility within organisations. Sharp (1999) stresses that the ability to adapt depends on two kinds of factors: *externally* the companies must be plugged into key information and learning networks and *internally* it demands high levels of delegation and short chains of decision.

In the perspective of NIS Edquist outlines *interactive learning* as an important target of innovation policy. He suggests to use procurement policies used in networks to improve the interactive user-producer relations (Edquist 1997 and 1999). Surprisingly, the discussion of learning as a key concept in innovation often does not refer to the large management literature on organisational learning. For an exception, see Ciborra 1992; see also Harding 1995, pp. 16-20

The importance of training of researchers in RTOs is being underlined by several authors because of the stock of knowledge they carry into private sectors of the economy, if they change jobs (training externalities) (Pavitt 1991, Brooks 1994, Dasgupta / David 1994). The increasing attention dedicated to processes of learning as a mechanism of transferring tacit knowledge emphasises the role of research institutions in providing human skills which enable firms to absorb knowledge gained from various sources (Lundvall 1999). Faulkner and Senker emphasise the advantages of personal contact over other forms of linkage on the basis of statements of company representatives (Faulkner / Senker 1994). This supports Lundvall's view on *learning-by-interacting* (Lundvall 1992) and Sharp's conclusion on the effectiveness of common research projects for knowledge diffusion (Sharp 1999).

The emphasis on learning as the basis of a knowledge society leads to the question of the role of RTOs and other NSI actors in enhancing learning and learning capablities.

Despite the diversity of NSIs and of the character, functions and dynamics of change in RTOs of different countries, there is a common denominator in the challenges facing research, knowledge and innovation systems in each country. The *Globalising Learning Economy* sets the framework for these challenges (Lundvall/Borrás 1997).

It has long been accepted in innovation research that the innovation process is more complex than the production and transfer of R&D results. The concept of learning has therefore substituted the strong bias towards R&D in the innovation literature. The shift in emphasis from learning-by-doing (Arrow 1962) to learning-by-using (Rosenberg 1976) to learning-by-interaction (Lundvall 1992) marks the shift in research from technology to efficient technology adoption to networking and co-operation as success factors. Understanding how firms learn and finding ways of enabling them to learn seems to be the central concern of today's innovation research and innovation policies. In this context, the role of RTOs as facilitators and agents of learning has to be examined.

Nelson and Winter have developed the notion of routines to explain the absorption of knowledge in a firm's own set of capabilities and practices (Nelson/Winter 1982). Routines are sets of rules that enable a firm to react to challenges and change. Nelson and Winter argue that the performance of a firm will be determined by its routines and the routines at the disposition of other firms or organisations the firm interacts with (see also Nelson 1999). In a later publication with Sampat, Nelson develops the concept of routines by distinguishing between the 'physical technologies' aspects in routines and the 'social technology' aspects. The introduction of social technologies allows to analyse modes of co-ordination (Nelson /Sampat 1998). The major changes that accompany, enhance and cause the emergence of a knowledge-based economy go along with changes in routines for all actors in the NSI. Companies as well as innovation supporting RTOs will have to adapt their routines to changes occurring in their partner organisations.

The evidence on the nature of innovation processes in firms suggests that the realisation of innovations involves a whole range of inputs or functions. These functions will partly be provided in-house by the innovating company, partly outsourced to RTOs or KIBS. The profiles of RTOs and KIBS determine the division of labour in contributing to innovation functions between them. However, changing profiles of RTOs and new service products offered by KIBS might change this division of labour and eventually lead to a new competitive regime in markets for innovation support, to revised public funding policies and to changes in the purpose and service mix offered by RTOs that goes beyond the production of R&D results.

5 Conclusions

The current configuration of RTOs as actors in NSI has to be re-examined from the perspective of an emerging knowledge economy in a European and an international context. The effectiveness of NSIs relies to a large extent on their ability to change their institutions in response to new requirements in the economy, in competitive regimes and - more specifically - in the innovation process (Edquist 1999). The shift from an institutional to a functional perspective in identifying service products and service suppliers in the innovation process will open up new ways of understanding the mechanisms driving innovation in the context of service economies. The following aspects make a revision of the existing institutional and political settings necessary:

- The diversity of RTOs and their changing roles in NSI makes an institutional and organisational analysis of NSIs alone inadequate for the understanding of innovation processes. The emergence of new service requirements and of new actors to fulfil them directs attention to a functional approach in the study of services provided by research institutions in the NSI.
- RTOs have been designed to serve the purposes of national industries in a national political context. This casts doubts on their effectiveness in an international setting.
- Budget deficits require the reduction of government funding. As a consequence new sources and mechanisms of funding research have to be explored.
- The research agenda of RTOs has often developed from the internal logic of self-referential processes of scientific progress thus neglecting the coupling with the industrial world.
- The organisational structure of RTOs, their embeddedness in civil service configurations often leads to inflexible modes of reaction to new challenges, and limits the possibility of reforms of industrial relations, career paths and incentive systems.
- The success of innovation is increasingly dependent on functions that are *not* R&D, like organisational re-adjustments, training of personnel, design of prototypes and procedural blue-prints, market research, availability of venture capital, integration of existing equipment and stocks of knowledge with new knowledge inputs.
- Lean-production models and the need for companies to react extremely quickly and flexibly to new innovation cycles have led to innovation strategies which rely more and more on the outsourcing of innovation related services.
- Innovation support in the form of a wide range of service functions emphasises demand-driven service supply in the innovation process as opposed to the supply-driven scenarios in traditional R&D biased innovation models.

There is evidence that these aspects have resulted in the evolution of a set of knowledge-intensive business services that bridge the gap between the capabilities and capacities of RTOs and the needs of innovating companies. This phenomenon is a prominent feature of the differentiation of service sectors in the building-up of a knowledge-based service economy. Competition for funds, overlapping competencies and processes of market consolidation as well as of institutional reforms in the public sector are causing major changes in the division of labour between RTOs, KIBS and industry. They are also changing the nature of RTOs themselves. The future configuration of NSIs with respect to roles and functions of RTOs and KIBS will be determined by the question which solution provides the best support for companies in facing the challenges of learning to be fit for the knowledge-based economy.

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