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FRAUNHOFER ISI'S SYSTEMIC RESEARCH PERSPECTIVE IN THE CONTEXT OF INNOVATION SYSTEMS

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1.1 Looking back: origins of the systemic perspective

Back in the year 1972, when the Fraunhofer Institute for Systems and Innovation Research ISI (Fraunhofer ISI) was founded, its founding father and first director, Helmar Krupp, published a study entitled "The function of the Fraunhofer Society in the Innovation System of the Federal Republic of Germany". In this study he painted a picture of the research and innovation landscape of Germany by describing the "subjects" individuals, teams, education, industry, public R&D organisations, financial system, public authorities, and international organisations (Krupp 1972, p. 36). With regard to the role of the Fraunhofer Society (FhG) in the West German innovation system he concluded: "Such an innovation system provides the framework within which the exact location of the FhG can be determined. Each objective of the FhG should assume that it contributes to applied research to structure the innovation system in the area between research and society, and show the form in which that could happen. Conversely, the innovation system provides efficiency criteria" (translation of Krupp 1972, p. 36). He expanded this view by stating "this scheme illuminates the diversity and complexity of transfer processes, the communication graphs, which contribute to innovation systems" (ibid., p. 36). It can thus be concluded from his orientation towards a national model of innovation that, since the beginning, Fraunhofer ISI has been following a systemic innovation research perspective.[1] At a time when the concept of national innovation systems had not yet been developed in the way it is understood today, a similar perspective was introduced by Helmar Krupp and applied to the German situation. This is one of the examples of the pioneering work of Fraunhofer ISI and its contributions to the scientific advancement of innovation research and innovation policy research.[2]

Many of the facts which are commonly understood today were either new or had not yet been discovered in the 1960s and early 1970s. In 1966, Jacob Schmookler published his seminal book on "Invention and Economic Growth" (Schmookler 1966). Contrary to the economic mainstream, which built on the work of Joseph Schumpeter as the representative of a supply-driven innovation approach, by using empirical data Schmookler discovered that there is a high correlation between the investments in new products and patent intensity and concluded that innovation activity and demand behaviour are closely related. Increases in investments occur earlier than increases in patenting. While "[...] most economists have traditionally regarded business firms and government as the prime sources of dynamic happenings, [...] demand factors may also prove the most common cause of the invention of a radically new product [...]" (Schmookler 1966, pp. 179, 204).

Regarding the question whether innovations are supply- or demand-induced, Schmookler's work is often used as a contraposition to Schumpeter (cf. Coombs et al. 1987, p. 96). According to Schmookler, changes in demand strongly influence technological development and the differentiation of economic activities (cf. Grupp 1998, p. 80). The major value of his research is the fact that he understands the process of invention not only as a technical and scientific supply phenomenon, but emphasises on the influence of the demand side (Schmookler 1966, p. 183). The subsequent discussions of both approaches have led to the consensus that both "technology push" and "demand pull" in mutual interaction can be driving forces in the innovation process (cf. Kromphardt and Teschner 1986, p. 237).

This aspect is important as, during the early 1970s, at least as can be seen in the publication by Helmar Krupp, innovative activity was regarded as a mainly technical process where the management of a company could predetermine the areas and directions of innovation. Furthermore, innovations were assumed to be generated

1 In this contribution, innovation as the central constituent of the innovation system approach is defined as an interactive process of the transformation of information, implicit and explicit knowledge into new products, processes, organisational and social behaviours and structures. Innovation processes can be incremental or radical, they have technological, organisational and social character, and they are context specific, because socio-cultural factors significantly influence the ability, kind and intensity of interactions between the different actors in the innovation process and the learning processes between them (Koschatzky 2001, p. 62).

2 Fagerberg and Sapprasert (2011, p. 673) wrote: "Although Freeman was the first to use the term in a publication, he was quick to point out that: 'according to this author's recollections, the first person to use the expression "National Systems of Innovation" was Bengt-Åke Lundvall (Freeman 1995, p. 5)'". It should not be discussed here who was the first to use the term, but there is no doubt that Helmar Krupp was one of the first.

by a chain of mainly rational decisions, and research and development plays a predominant role. This view is reflected by a reference Helmar Krupp made to an OECD publication in 1971 titled "The Conditions for Success in Technological Innovation" (OECD 1971). The OECD publication is a good indication of the understanding of innovation processes at that time and the need to improve both theoretical and empirical knowledge in innovation economics and innovation research.

The first empirical studies analysing innovation characteristics and innovation differences at the industry level were carried out in the late 1960s. One of the most prominent studies was the SAPPHO project, in which 43 pairs of both successful and unsuccessful innovations in the chemical industry and the manufacture of scientific instruments were analysed regarding their success and failure factors (cf. Freeman et al. 1971; Rothwell et al. 1974). It turned out that successful technological development depends on a thorough knowledge of user needs and conditions of use, coordination of the development, production and marketing activities in the company, incorporating external information and advisory services for science and technology, basic research in the company in cooperation with external research institutions (e.g. universities). This shows that, as early as the 1960s and 1970s, it was assumed that innovation cannot be carried out in isolation, but is supported by an interactive environment.

Hence, interactivity and linearity were the main inputs to the first systemic models of the structure and components of (technological) innovation processes. In his study published in 1972, Helmar Krupp not only used the term "innovation system", but also described a model developed by Mottur (1968) which integrates the linear innovation process in an environment formed and influenced by the socio-economic system (e.g. programmes, projects, policies) and the science and engineering educational system (science and engineering knowledge, technological-industrial knowledge). Feedback loops already existed then as well as the use of technological innovations as an important feedback channel (cf. Figure 1–1).

This systems model and its description of the different functions and interactions shows parallels with the chain-linked model published by Kline and Rosenberg in 1986 (Kline and Rosenberg 1986), although this later model is more focused on the innovation process itself, while the Mottur model connects innovation with higher systemic frameworks like the economic or educational system.

1.2 Innovation systems – different perspectives

Nevertheless, the dominant paradigm in both technology transfer and innovation was the linear model. According to this view, the innovation process consists of a sequence of individual stages, ranging from idea generation, research, development, to production and marketing, which usually have little or no overlap and which form discrete and distinguishable units (cf. Kay 1979; 1988). In the understanding of this sequence, marketing an innovation is followed by its diffusion, where the latter can occur either through imitation or adoption (cf. Davies 1979, Metcalfe 1981).

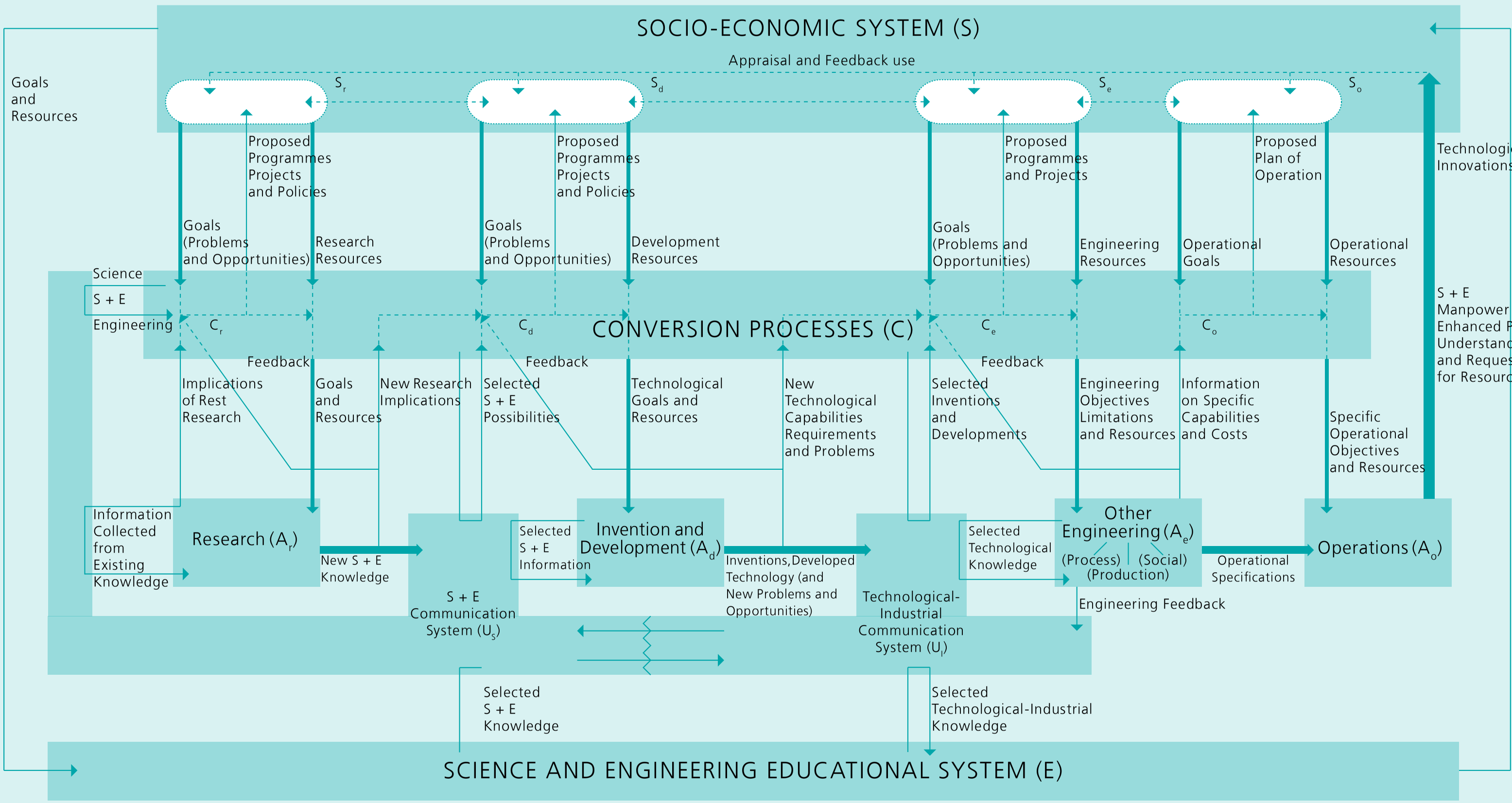
Two generations of linear models can be distinguished (Rothwell 1992; 1993; 1994):
- the "first generation: technology push" models of the 1960s, which emanate from a technology-driven innovation activity and
- the "second generation: need-pull" models of the 1970s (e.g. Utterback 1974), which regard innovation as a result of market and demand-induced R&D activities

Although the first foundations had already been laid in the 1960s, system approaches in innovation research gained considerable importance during the 1970s and 1980s due to clear insights into the economics of innovation (e.g. in terms of the innovation patterns of SMEs, the importance of technological trajectories, the cumulative character of technological change), and the development of new ideas about the complexity and non-linearity of innovation processes (cf. Nelson and Winter 1977; Freeman 1982; Dosi 1982; 1988). Based on the ideas of Friedrich List about the German national transport system and the national system of political economy (List 1838; 1841), which, among other aspects, dealt with the optimisation of production and the development of national infrastructure and institutions, Christopher Freeman developed the concept of a "national system of innovation" (Freeman 1987). He developed List's idea further by considering it necessary that the national government promotes the technological infrastructure of a country.[3] He assumes that short-term strategies (such as wage or exchange rate changes), however, have only limited effects on strengthening the international competitiveness of an economy.

The most important characteristics of systems of innovation are summarised in the definition by Edquist, who wrote that innovation systems are defined by "[…] all important economic, social, political, organisational, institutional, and other factors that influence the development, diffusion, and use of innovation" (Edquist 2005, p. 182). During the late 1980s and especially during the 1990s, complex analyses of the national framework conditions for technology development and diffusion, technical change, and innovation and learning were carried out (e.g. Dosi et al. 1988). Lundvall (1992), for example, made important additional contributions to the theoretical advancement of the concept. The major focus lay on the institutional set-up defined by national boundaries and the interaction processes which influence the innovation actors and which stimulate learning processes. According to him "[…] a system of innovation is constituted by elements and relationships which interact in the production, diffusion and use of new, and economically useful, knowledge and […] encompasses elements and relationships, either located within or rooted inside the borders of a nation state" (Lundvall 1992a, p. 2). Significant subsystems that both influence and include learning, searching and exploring are the production system, the marketing system and the financial system (ibid., p. 12). With regard to learning and innovation, two influencing factors, whose framework is set by the nation-state, play an important

3 Freeman emphasised the role of List by stating that "List's book on 'The National System of Political Economy' might just as well have been entitled 'The National System of Innovation' since he anticipated many of the concerns of this contemporary literature" (Freeman 2002, p. 193).

Figure 1–1: The process of technological innovation



r = research   d = invention and development   e = other engineering   o = operations   s = Science and engineering   i = Technological-industrial

Source: adapted from Mottur (1968, p. 124) role, namely a common cultural background and the institutional structure. Spatial and cultural proximity promote learning and exchange processes (Schmoch et al. 1996, p. 125). As a matter of fact, social and cultural factors influence the successful implementation of innovation processes. The institutions of a country also reduce innovation- and market-related uncertainties (Lundvall 1992a, p. 10).

Nelson and Rosenberg (1993, pp. 4–5) split the term national innovation system into its three components and define innovation as a process which puts the company in a position to manufacture products and manage production processes that are new to it, to the country or even to the world. System is understood as a set of institutions whose interactions influence the innovation performance of the national companies. The system does not have to have been fully developed, nor do the institutions have to work together in a smooth and coordinated way. Regarding the term "nation", Nelson and Rosenberg point out that even within nations the institutional structures in different technology fields differ significantly from each other and that the common denominator of these institutions is their transnational rather than their national orientation.[4] This raises the question whether the concept of a national innovation system makes any sense at all. The answer is that, despite international technology development and diffusion, institutional and cultural factors have a specific national expression and can significantly influence technological change. These influences are stronger or weaker depending on the size of a country and the globalism of techno-economic systems, and still justify the use of the nation state as the unit of analysis, although transnational innovation systems and their effects on national innovation policies should not be excluded (Nelson and Rosenberg 1993, p. 16).

While this discussion has anticipated the recent debate about the appropriateness and relevance of a national concept in a globalised world (e.g. Freeman 2002; Carlsson 2006), it also stimulated the development of innovation system approaches at two other ends of the spectrum: the sectoral/technological and the regional dimensions. In all of these specific forms of innovation systems, the delimiting factors are sectors, technological fields or spatial entities below the national level. Technological innovation systems are defined "[...] in terms of knowledge/competence flows rather than flows of ordinary goods and services. They consist of dynamic knowledge and competence networks. In the presence of an entrepreneur and sufficient critical mass, such networks can be transformed into development blocks, i.e. synergistic clusters of firms and technologies within an industry or a group of industries" (Carlsson and Stankiewicz 1991, p. 111). A sectoral innovation system is a "group of firms active in developing and making a sector's products and in generating and utilizing a sector's technologies" (Breschi and Malerba 1997, p. 131). Malerba's (2002, p. 250) definition is "a set of new and established products for specific uses and the set of agents carrying

4 "The system of institutions supporting technical innovation in one field, say pharmaceuticals, may have very little overlap with the system of institutions supporting innovations in another field, say aircraft. On the other hand, in many fields of technology, including both pharmaceuticals and aircraft, a number of the institutions are or act transnational" (Nelson and Rosenberg 1993, p. 5).

out market and non-market interactions for the creation, production and sale of these products". According to Malerba (2002, pp. 250–251) the basic elements of sectoral systems are products, agents (firms, universities, financial institutions, central government, local authorities, individuals), knowledge and learning processes (differentiation across sectors, impacts on innovative activities, organisation and the behaviour of firms and other agents), basic technologies, inputs, demand, and the related links and complementarities, mechanisms of interactions both within firms and outside firms, processes of competition and selection, and institutions (such as standards, regulations, labour markets). The sectoral innovation system thus focuses specifically on the framework conditions in a particular industry. It consists of a knowledge base, technologies, inputs, and an existing, emergent and potential demand. The concept emphasises that actors belonging to a certain sector have sector-specific knowledge and use sector-specific technologies, and that market relations, the institutional context, actors' behaviour, etc. are specific to these sectors.

The concept of regional innovation systems, developed by Cooke (1992), is based on the notion of localised knowledge and the specific endowment of regions with institutions, organisations, and networks which influence the generation and diffusion of innovations. A regional innovation system is therefore "[...] typically understood to be a set of interacting private and public interests, formal institutions, and other organizations that function according to organizational and institutional arrangements and relationships conducive to the generation, use, and dissemination of knowledge" (Doloreux and Parto 2005, pp. 134–135). Regional systems respond to different rationales, institutional and governance settings which can be found at the sub-national territorial level and are thus context-specific. It is a distinct element of the concept that a region does not offer all the factors and institutions necessary for innovation, but that it is part of a superior, i.e. national system, and has to cooperate with other regional or national systems in order to merge all the necessary resources in the specific territory (Cooke et al. 2004; Asheim and Gertler 2005).

All these studies are a reflection of an evolutionary innovation perspective, according to which innovation is not a homogeneous process, but exhibits technological and socio-cultural peculiarities which can, in turn, be of a national, regional, and also international nature.[5] Due to the diminishing influence of nation states on multi-national enterprises operating from their territory (Dunning 1988), and the transnational and transcontinental character of new technologies,[6] the specific assets of countries and their potential as competitive scientific-technological locations become the centre of interest (cf. Koschatzky 2001). In this context, it was underlined by Michael Porter that the national environment and the home base of companies is an

5 "Processes of innovation transcend national borders and sometimes they are local rather than national" (Lundvall 1992a, p. 4).

6 "There is good reason to believe that in recent years, just as the idea of national innovation systems has become widely accepted, technological communities have become transnational as never before" (Nelson and Rosenberg 1993, p. 17).

important condition for globalisation processes.[7] On the one hand, national supply conditions of human capital and R&D infrastructure as well as the general location conditions affect the competitiveness of enterprises, while, on the other hand, the home market of at least the major economies is an important test market to improve the product attributes and thus to facilitate the entry into other markets (Porter 1990, pp. 63–64). While a national or a regional innovation system can easily be defined by national or regional geographical boundaries, and more recently, also by the degree of stickiness and the kind of knowledge base and its relation to proximity (Asheim and Gertler 2005, p. 310), the definition of a sectoral innovation system depends on sectoral delimitations which can be applied at different levels of granularity (e.g. the two, three or four digit level of industrial branch classifications). Technological innovation systems are even more difficult to define, because there is no commonly accepted definition of certain technologies. Technological innovation systems are therefore more difficult to grasp. Nevertheless, the advantage of this heuristic concept compared to spatial or sectoral innovation systems is that it contains the inherent aspect of a dynamic component. Technological systems not only incorporate parts of national, sectoral or regional systems, but include the dynamic dimension of technological change. While a major criticism of the innovation system concept, its static character, mainly applies to national, regional and sectoral approaches, the dynamic characteristic of technological systems makes this concept the basis for recent advancements in technological innovation systems (Hekkert et al. 2007). This new line of discussion shows that technological innovation systems follow different rationales compared to their spatial or sectoral counterparts. Some of the new ideas will be discussed later in this chapter.

1.3 Central characteristics and heuristic concepts of innovation systems

Components and relations

Although some definitions of innovation systems have already been presented, the general characteristics of a "system" still need to be discussed. With reference to Ingelstamm, Edquist points out that "a system consists of two kinds of constituents: There are, first, some kinds of components and, second, relations among them". Besides, "the system has a function, i.e. it is performing or achieving something." And, the third aspect is, "it must be possible to discriminate between the system and the rest

7 "The role of the home nation seems to be as strong as or stronger than ever. While globalization of competition might appear to make the nation less important, instead it seems to make it more so. With fewer impediments to trade to shelter uncompetitive domestic firms and industries, the home nation takes on growing significance because it is the source of the skills and technology that underpin competitive advantage" (Porter 1990, p. 19).
Globalisation and regionalisation are not a contradiction, but parallel processes: "[…] regionalisation is a tendency taking place parallel to globalisation. The regionalisation perspective further represents an alternative development model for local industrial development, with clear implications for what are important tools in local level policy" (Isaksen 1998, p. 40).

of the world" (Edquist 2005, p. 187). So the system must be specific and identifiable.

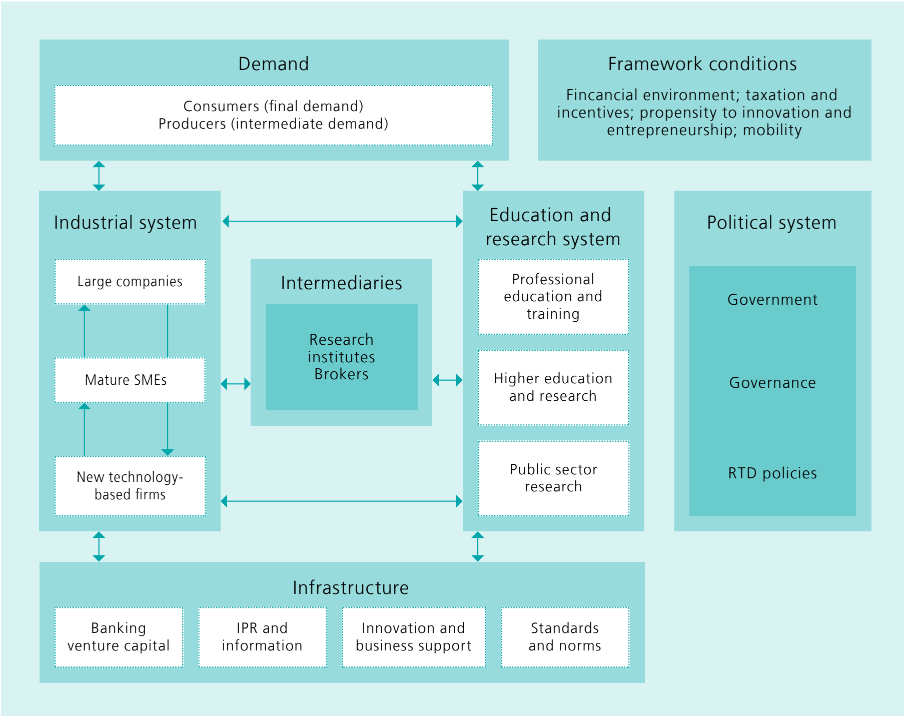
The components consist of a bundle of organisational actors and actor groups and institutional rules defining the "rules of the game". Both actors and rules have a pertinent function for the success of innovative efforts (ibid., p. 186). According to Nelson (1993, pp. 517–520) and Patel and Pavitt (1994), innovation systems are made up of four main elements:

1. The institutional structures of a country, region or sector: they are formed by companies, universities, research and training organisations, norms, routines, networks, financial organisations, and the policy of promoting and regulating technical change.
2. The incentive system of a country, region or sector. This includes, among others, incentive systems for innovation, technology transfer, learning and qualification, business formation and job mobility within and between organisations.
3. The skills and creativity of innovation and economic actors in a country, region or sector. Both between and within countries and between companies in a country there are great differences in the diversity and quality of products and services and opportunities to forge new paths of development.
4. The cultural peculiarities of a country, region or within a sector which are reflected, for example, in the different acceptance and user understanding of technologies.

These central characteristics form the basis of different interpretations of innovation systems and are usually adapted according to specific application needs. In many cases, heuristic models of innovation systems are built around the general institutional structures of countries, regions or sectors. One example of an innovation system model often used and extended in studies by Fraunhofer ISI is that developed by Kuhlmann and Arnold (2001) in their study on the role of the research Council Norway in the Norwegian innovation system (cf. Figure 1–2). This model focuses on the two main sub-systems industry and education/research, and links them through the active role of intermediary organisations. These sub-systems are influenced by and themselves influence the demand system, the framework conditions and the existing infrastructure system, and are shaped by the political system.

As already pointed out, not only the amount, quality and composition of organisational actors matter, but also the content, intensity and quality of their relations. Interactions and networks as a specific form of transactions are additional, important features of an innovation system. Both interactions and networks can take different characteristics and are described in the extensive literature on network economics and innovation networks (for an overview, see Liefner and Schätzl 2012, pp. 135–142; Koschatzky 2001, pp. 133–155). A classical feature is the distinction between strong and weak ties. Strong ties to one or only a few partners are characteristic for production-oriented networks, where larger companies bind suppliers closely to them, or for cooperations in which the number of potential partners is limited a priori. According to Granovetter (1973; 1982), the strength of relationships depends on the effort that is required for their upkeep.

Figure 1–2: Heuristic model of an innovation system



Source: adapted from Kuhlmann and Arnold (2001, p. 2)

The weaker the effort made in the fostering of relations, the weaker is the binding intensity, but the higher the number of possible contacts. In terms of innovation-relevant relationships, "strong ties" limit the number of potential partners and potential diffusion channels for information and innovation. Granovetter argues that "weak ties" bridge social distances more easily and thus allow easier contacts to a larger number of partners than is possible by "strong ties" (an effect called "loose coupling" by Weick 1976). So there is wider access to information and a greater choice of diverse knowledge sources. For innovation networks this means that "weak ties" reduce the risk of dependencies on individual partners, but at the cost of the increased risk of opportunistic behaviour, because, in soft relationships, sanctions for violating the rules of the game are hardly effective because of the variety of available options.

Besides the strength of ties, their purpose and content are also relevant features. Not only information can be transferred via collaborative ties between different actors and organisations, but also knowledge in its different forms (e.g. implicit or tacit and explicit or codified knowledge, knowledge about facts ("know-what"), about natural laws and social principles ("know-why"), about abilities ("know-how"), and knowledge about those who know how to do things ("know-who"), synthetic knowledge related to engineering know-how, or analytical knowledge related to scientific know-why; cf. Nonaka 1994; Foray and Lundvall 1996; Asheim and Coenen 2005). In cases where highly valuable (and competitive) tacit analytical knowledge is exchanged in (parts of) innovation systems and utilised in innovation projects, it can be assumed that the output of the innovation system differs positively from others in which this kind of knowledge is not subject to collaborative ties.

A specific role of "relation" affects the exchange of the political system with the other sub-systems. It is expected that the political system plays an active role in shaping the whole innovation system, in making it coherent and in developing it further. Nevertheless, its politics do not act in isolation, but are simultaneously influenced by the other sub-systems in an interactive way. This role (or function) within an innovation system makes the model so popular in the political field. It not only provides a good overview of the main fields of innovative activity, but attributes an active governance function to the political system. The basic assumption of the innovation system concept is that the growth and competitiveness of a given economic unit (country, region or sector) is determined by the networking and innovative abilities of its companies. These abilities as well as the supporting infrastructure can be influenced by the public administration (political system) by promoting the interaction, networking and learning between the different sub-systems and their actors (Storper and Scott 1995, pp. 513–518). This support (or intervention) does not improve only the intensity of linkages, but also their quality and their output and, in sum, the innovation system itself. In cases of system fragmentation, the inherent message of the innovation system approach is therefore that an intensification of collaboration within and between the sub-systems can mobilise new learning potentials and thus increase creativity and innovative output. Besides this general message, the concept does not provide indepth recommendations for specific policy instruments and programmes. Nevertheless, using the regional innovation system approach as an example, five steps are recommended in order to stimulate network mobilisation (cf. Cooke 1996, p. 168; Koschatzky 2001, p. 179):

1. Identification and involvement of actors ("stakeholders") who are committed to bringing in financial and human resources. These can be individuals or organisations of the innovation infrastructure.
2. Formulation of an innovation strategy based on an analysis of the supply of innovation-supporting services and the implicit and explicit demand of the companies.
3. Setting of standards and promotion of continuous quality improvement, both in production and research.
4. Sectoral focus of the measures in order to achieve largest possible effects with limited resources.
5. Development of skills for the development and management of networks and for innovation support.

These steps are far from being precisely formulated policy measures, but aim to illustrate that the governance dimension is also discussed in the innovation system literature (cf. for example Uyarra 2010 with regard to regional policy). This discussion also addresses the question whether public intervention is justified by either system or market failures (Woolthuis et al. 2005; Dobrinsky 2009). The argument is that, for example, systemic insufficiencies like path dependencies, missing abilities to adapt to new technological paradigms, or deficiencies in regulatory frameworks or social institutions justify the use of innovation policy instruments.

Functions

The analysis and understanding of innovation systems is not only directed towards their organisational actors and the interactions between them, but also towards the functions the actors and the whole system fulfil. The major function of the innovation system itself is to stimulate innovation and increase the innovative output in order to secure and increase employment and social and economic wealth. The literature on innovation systems provides a broad set of functions which a system should accomplish. Edquist (2005, pp. 190–191) lists the following ten functions (which he calls activities): (1) provision of research and development (R&D) and creating new knowledge, (2) competence building like the provision of education and training and human capital creation, (3) formation of new product markets, (4) articulation of quality requirements, (5) creating and changing organisations relevant for innovation, (6) networking including interactive learning, (7) creating and changing institutions that influence innovating organisations and innovation processes, (8) incubating activities, (9) financing of innovation processes and facilitating the commercialisation of knowledge, (10) provision of consultancy services relevant for innovation processes. These activities are not equally important in all innovation systems, but their relevance varies according to the kind of innovation system (national, sectoral etc.) and also over time.

According to Johnson (2001; cited in Hekkert et al. 2007, p. 419), innovation systems should fulfil eight functions: (1) supply incentives for companies to engage in innovative work, (2) supply resources (capital and competence), (3) guide the direction of search (influence the direction in which actors deploy resources), (4) recognise the potential for growth (identifying technological possibilities and economic viability), (5) facilitate the exchange of information and knowledge, (6) stimulate/create markets, (7) reduce social uncertainty (i.e. uncertainty about how others will act and react), (8) counteract the resistance to change that may arise in society when an innovation is introduced (provide legitimacy for the innovation). Hekkert et al. (2007, pp. 421–425) propose seven functions that can be applied to map key activities in innovation systems: (1) entrepreneurial activities, (2) knowledge development, (3) knowledge diffusion through networks, (4) guidance of the search, (5) market formation, (6) resource mobilisation, (7) creation of legitimacy/counteract resistance to change.

While the functions listed by Edquist seem to be closer to the "classical" understanding of the innovation system model (e.g. as described in Figure 1–2), both Johnson and Hekkert et al. have a less organisational view, but their functions are more related to a systemic model in which general characteristics of the innovation process are used to analyse the interactions among the functions and their impact on the economic output of the system, namely on entrepreneurial activities. Hekkert et al. (2007, p. 422) therefore state that "the presence of active entrepreneurs is a first and prime indication of the performance of an innovation system." Besides the entrepreneurial sector, their functions do not originate from the role of the other sub-systems of an innovation system, but are more superior in character. The function "guidance of the search", for example, can be seen as the sum of activities by different system components that "[…] positively affect the visibility and clarity of specific wants among technology users" (Hekkert et al. 2007, p. 423). Although the demand function was already included in the "classical" model, it was not included in the list of activities given by Edquist (2005). It is especially this aspect, together with the more socially/individually based functions of the reduction of social uncertainty and the counteraction of resistance to change that distinguish the understanding of these superior (or system inherent) functions from the general understanding of functions directly related to specific elements of an innovation system.

Besides these differences, this short review of the role of functions in and of innovation systems makes it clear that it is not only necessary to examine the organisational set-up and the linkages between the different organisations, but also to analyse the functions these organisations fulfil together with those functions that emerge from the different inherent features of contemporary innovation processes and the need to organise innovation processes in a competitive and sustainable manner.

Delimitations and openness of innovation systems

While at the national level there is generally no doubt that the organisational set-up and the interactions between the different stakeholders in innovation processes constitute the existence of an innovation system, this is much less clear when it comes to the level of regions (as sub-national entities) or sectors. The merit of the innovation systems approach is that the formulation of an analytical conceptual framework to analyse empirical evidence from individual case studies allows general conclusions to be drawn about the systemic elements of the innovation process. At both the regional and sectoral level, significantly higher diversity can be observed and the system concept is to be questioned far more than on the national level.[8] It therefore depends on empirical tests whether the respective unit of analysis (region, sector) meets the system criteria and whether it is possible to detect the central elements of the system and their interactions. In its general validity objective, the innovation system therefore describes ideal innovation systems and is thus a hypothesis which has to be tested for each individual case (Koschatzky 2001, p. 184). Not every region or sector is therefore an innovation system, and not all of these innovation systems can exist alone and independently of other innovation systems. Many smaller units fulfil either specialised functions in national innovation systems (regions, sectors) or in supranational settings (mainly sectors), without whose existence they would be not operational. This aspect of "landscape" was included in some of the more recent innovation system approaches (cf. Markard and Truffer 2008, p. 597). The openness of the "system" and

8 According to Cooke (1998, p. 17): "[…] very few regions have all the attributes of a RIS (regional innovation system) […]". For the political implications cf. Tödtling and Trippl (2005).

its interrelations with other systems is of course not only a requirement for smaller units; nations and supra-national entities do not operate in isolation either (Carlsson 2006). Interfaces to other systems are therefore a fundamental requisite and have to be included in empirical analyses. The growing "leakiness" of innovation systems and their dependence on international developments has therefore become an important characteristic over the last few decades (ibid., p. 65).[9]

Synthesis of the elements of innovation systems

Taking the heuristic approach of innovation systems and their major constituents as a conceptual framework of analysis (Edquist 2005; Malerba 2002), Table 1–1 summarises all the elements which are classically considered to be important or constitutive for any innovation system and which can thus be subject to both spatial (national and regional) and sectoral/technological factors of influence (cf. Koschatzky et al. 2009).

While some aspects, such as the form of competition, are sectoral- or technological-specific, they can, of course, also be the result of the national or regional business culture. The impact of relevant policy measures, on the other hand, which is considered a spatial (national/regional) characteristic in many studies, is increasingly complemented by the influence of transnational, sector- or technology-specific policy frameworks, e.g. the Joint Programming Initiatives at the European level. While policies are designed from both sectorally focused and cross-sectoral perspectives, it depends to a high degree on the specific national/regional environment whether sectoral or cross-sectoral policies play a more decisive role on at the level of policy-making (transnational, national, regional) at which they are designed. For many other constitutive elements, such as agents and organisations, interactions, knowledge base, human capital, and institutions, the double and interrelated importance of sectoral and spatial specificities becomes even more evident from the examples given in Table 1–1. Even for the impact of technological trends, which is often given as a key argument for the high(er) importance of the sectoral approach, the multi-level framework concept of "niches" and the influence of regimes and the landscape show that technological developments can also be related to the "environmental" setting from which they emerge.

1.4 Reflections and critique

The criticisms regarding different aspects of the innovation system concept can be summarised as follows (cf. Bokelmann et al. 2012, pp. 32–33):

- The innovation system concept is a (normative) hypothesis. It describes how structures and interactive relationships are embodied in the ideal case. Whether the investigated case has all the attributes of an innovation system cannot be determined ex ante, but will be the result of the study itself.
- The systemic nature of innovation (which is however not universally given) is an essential feature of the concept, but a relation to value added chains within innovation systems is not postulated. Value added chains will have to evolve as a

9 The interdependencies of national, regional and international systems of innovation are discussed by Fromhold-Eisebith (2007).

Table 1–1: A sectoral-territorial approach to the analysis of innovation systems

Innovation System			
Elements	**Territorial dimension**		**Sectoral dimension**
	regional	**national**	**sector/technology field**
Agents and organisations	regional governance bodies, regional education institutions	national governance bodies, national education institutions, national IPR administration	MNEs, international standardisation bodies, international IPR administration, (international) branch associations
Interactions	local cross-sectoral networks	national cross-sectoral networks	international intra-MNE interactions, communities of practice
Knowledge base	localised tacit knowledge (specific, application-related, cross-sectoral)	codified knowledge (general, basic research related, cross-sectoral)	codified knowledge, tacit knowledge in intra-MNE networks, tacit knowledge communities of practice
Human capital	regional labour pool	national labour pool, mobility of labour force	specialised labour market, cross-sectoral mobility of labour force
Institutions	regional laws, regional governance	national laws and regulations, national governance	international treaties, international norms and standards
Policies	regional innovation policies, education policies	innovation policy, education policy	transnational ICT sector oriented policies and policies aiming at IT skills
Technologies and demand	regional laws on technology, regional acceptance of technology, regional buying power, regional demand caused by industry structure	national laws on technology, acceptance of technology in society, position to lead markets	factual trends in leading edge technology development
Competition and selection	regional economic characteristics: presence of competitors in the field, spirit of competition, entrepreneurial spirit, foundation aptitude	national economic characteristics: anti-trust legislation, bankruptcy legislation	sectoral specificities, firm size, position in product/service life cycle, mobility of product/service, degree of specialisation

Source: Koschatzky et al. (2009, pp. 8–9) based on Edquist (2005) and Malerba (2002) result of innovation processes, but are not related to the organisation of innovation processes (which are in the invention phase initially not value added oriented).

- Although the focus is on innovation, R&D is seen as a necessary requirement for the generation of innovations. The concept does not include a specific focus on or explanation of how innovations can be generated without inputs from the research sector, i.e. without formal R&D.
- Since no quantifiable thresholds exist from which interactive relationships sum up to an innovation system, there is wide scope for interpretation with respect to whether the object of study is an innovation system or not.
- Although the innovation system concept is based on theoretical and empirical evidence, it is in itself not a closed theory. It is a heuristic framework for the structural analysis and description of different innovation systems.
- A theoretical framework for the characteristics of different innovation systems does not exist. While the scientific basis is formed by the concept of national innovation systems, regional, sectoral or technological innovation systems are enhancements within the same conceptual framework. The assumptions that the casespecific environment influences the innovation patterns and that the innovation output can be improved by an intensification of the collaborative ties between the subsystems of an innovation system are essential for all facets of innovation systems.
- This aspect also describes the importance of public governance. According to the innovation system concept, it is the task of policy to create innovation-friendly conditions and the respective infrastructures, and to encourage networking between the different innovation actors (such as research collaborations, transfer bridges) so that diverse and successful interactions within and between the subsystems can develop which, in turn, increase the innovation output.
- Since the majority of analyses deal with territorial innovation systems at the national or regional level, models are quite similar regarding the institutional and organisational conditions in these territorial systems (cf. Figure 1–1). Different subsystems are identified, but only roughly outlined on the model level. It is up to empirical studies to fill these subsystems with content. Appropriate subsystems are borrowed for the analysis of sectoral innovation systems, but not explicitly offered.
- The concept allows static structural analyses and intertemporal comparison, as well as conclusions about the dynamics of the system. The concept itself is not dynamic. It represents a supply-oriented framework in which demand and user orientation play a certain, but not dominant role. Socio-cultural aspects are implicitly included, but only become visible by comparing different innovation systems. The concept also does not provide evidence regarding effectiveness in an innovation system. Interdependencies can only be determined by interpretation, but are themselves not included in the concept.
- Overall, the concept remains vague with regard to the specific conditions in each of the analysed cases. There is no detailed description of the required system components, especially regarding the different subsystems necessary. There is also no mandatory methodology for measuring the systemic characteristics of an

innovation system. Interactions are seen as a necessary condition, but how they should be designed and how they can be measured is not part of the concept.

– The concept of innovation systems as described above therefore provides only a rough orientation for empirical studies. The most relevant aspects, design of features and their measurement, are open questions which have to be answered by specific analyses. This fuzziness is a great weakness of the approach, but also makes it possible to flexibly adjust studies to the specific conditions of the object of analysis. The approach is therefore still popular and is also used in studies by Fraunhofer ISI as the different contributions in this book will show.

1.5 Recent interpretations of the innovation system approach

In recent years, not only the sustainability of an approach which highlights the role of nations in a globalised world has been questioned, but also its static character and the non-consideration of socio-cultural aspects and user demands in an environment in which these aspects are becoming more and more important. In recent contributions to this scientific debate, attempts have been made to develop multi-level conceptual frameworks for the comprehensive analysis of sectoral and technological innovation and for bridging the different territorial scales in innovation policies.

Major impulses arose primarily from the articles by Geels (2004), Hekkert et al. (2007) and Bergek et al. (2008). Important new elements are the multi-level perspective (MLP) defined by landscape, regimes and niches and the extension of sectoral innovation system approaches by integrating of a socio-technical system, the mission- and demand-oriented perspective as formulated by Geels (2004), the functional perspective of Hekkert et al. (2007) and Hekkert and Negro (2009) and the application of the functional approach in the context of technological innovation systems by Bergek et al. (2008).[10] As an attempt to merge the socio-cultural multi-level approach and the function-based technological system approach, the paper by Markard and Truffer (2008) argues that technological innovation systems must be complemented by the multi-level perspective with landscape, regimes and niches (see also Chapter 2 for a thorough discussion of this approach).

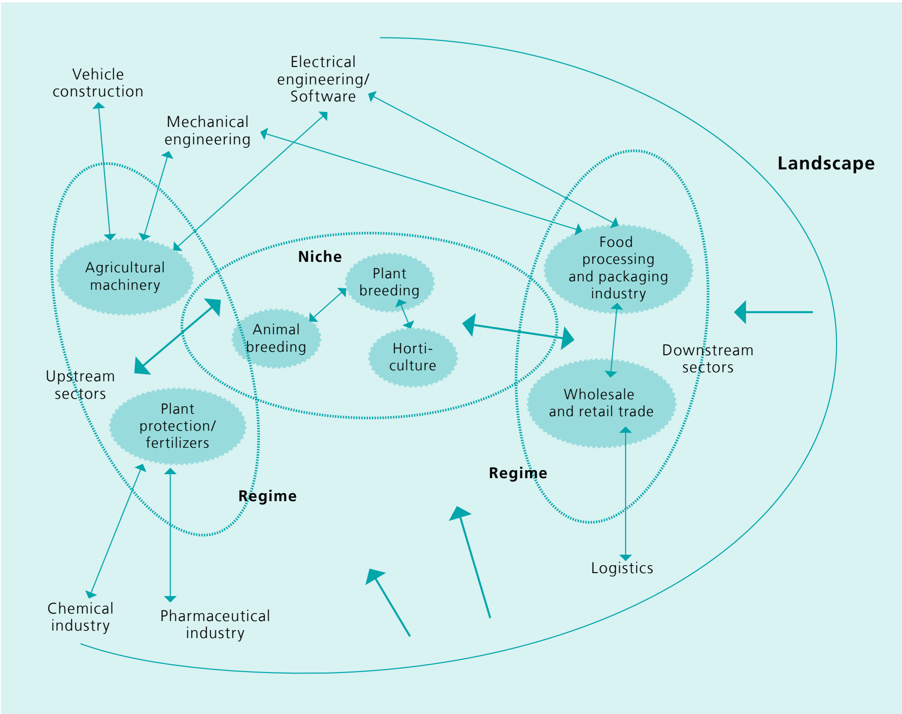
The landscape as the macro level "[...] includes a set of factors that influence innovation or transition processes but are hardly (or only in the long run) affected by themselves" (Markard and Truffer 2008, p. 603). A (socio-technical) regime is "[...] a coherent, highly interrelated and stable structure at the meso-level characterized by established products and technologies, stocks of knowledge, user practices, expectations, norms, regulations, etc. From the evolutionary perspective, a regime represents the selection environment for technological development in a certain field or sector, thus exerting a significant barrier for radical innovations to diffuse" (ibid., p. 603). The local level of innovation processes is defined by niches. They are "[...] commonly

10 Regarding the mission-orientation and the related demand perspective, e.g. by focusing on specific problems and user needs in the context of global challenges like demographic changes, poverty, energy consumption and environmental protection, reference can be made to the identification of the relevance of demand factors as impulses for innovations by Schmookler (1966).

referred to as protected spaces or incubation rooms, in which new technologies or socio-technical practices emerge and develop isolated from the selection pressures of 'normal' markets or regimes" (ibid., p. 605). Systemic change may occur through tensions in the socio-technical system, e.g. by changes in the landscape, and create windows of opportunities for inventions and innovations which subsequently create new regimes and foster the change of the system (cf. Geels 2004).

The multi-level perspective of innovation systems can be illustrated by applying this approach to the German agricultural socio-technical innovation system (cf. Figure 1–3).

Figure 1–3: Agricultural innovation in a multi-level perspective



Source: own draft according to Markard and Truffer (2008, p. 612)

The focal technological innovation system is composed of the three core elements of agriculture, namely plant breeding, animal breeding and horticulture, which are in themselves distinct niches with specific technologies and socio-technical practices (Bokelmann et al. 2012). Technological links exist, especially between plant breeding and horticulture, as well as between the two niches dealing with breeding technologies. Two dominant regimes exist on both the upstream and downstream side which strongly influence innovative activity and the use and diffusion of innovations in the agricultural core field. Two niches play the major role here: agricultural machinery and plant protection/fertilizers. They are not linked to each other but are closely linked to other sectors like vehicle construction, mechanical engineering and electrical engineering/software for machinery and the chemical and pharmaceutical industry for plant protection and fertilizers. Most of the agricultural technology is supplied by this upstream regime and innovation as such in agriculture is more oriented towards adaptation and efficiency improvements of these input technologies and less towards inventive activities. On the downstream side, weaker innovation impulses are generated by the food and the trade sector, because their focus is on further processing and product design rather than on input technologies for agricultural production (Menrad 2001). Overall linkages exist between mechanical and electrical engineering and the two upstream and downstream regimes via agricultural machinery and food processing and packaging machinery. The landscape can be defined by the demand for safe and cheap food, by agricultural and especially subsidy policies and by environmental and energy policies which have not only increased in importance over the last few years but which also reflect conflicts of interest in the use of farm land for food production, environmental protection and the production of biofuels.

These interdependencies between the different regimes and niches would not be as apparent if the classical sectoral innovation system model were used. The multi-level perspective allows conclusions to be drawn about dominant socio-technical regimes influencing innovation in the focal technological innovation system, in this case agriculture, and supports the empirical evidence that most of the new technologies and processes in agriculture are provided by the machinery and chemical industry. Systemic changes will therefore mainly be based on changes on the input side, on changes in the landscape and to a lesser extent on activities on the output processing side, and have to be responded to by the core agricultural production activities (cf. Bokelmann et al. 2012).

Besides these advantages, the multi-level perspective approach – at least at this level of analysis – includes functions and their interactions in order to understand technological change and innovation (Hekkert et. al 2007, p. 427), but does not provide insights into the organisational and institutional structures underlying and influencing niches, regimes and the landscape. These must be analytically determined for each case and cannot be built on a theoretical concept already incorporated into the multi-level innovation system perspective. This approach is therefore well suited to the analysis of individual technologies, but does not capture higher-level (policy) contexts. Due to the selective focus and complexity of multi-level structures, the results from this kind of analysis can be generalised only to a limited extent and are politically difficult to communicate.

1.6 Conclusions for innovation system analyses at Fraunhofer ISI

As explained in Section 1.1, Fraunhofer ISI was one of the first institutes to apply the systemic perspective in innovation research. During the last 40 years, many contributions have been made to advancements both in innovation economics theory and in empirical innovation research. The backbone of many studies was and still is the concept of innovation systems at the national, regional, sectoral and technological level. Advantages and disadvantages of the "classical" approach have been described in different parts of this chapter. A few years ago we started to discuss whether it is necessary to enhance the heuristic model we have been using for a long time and to create a new Fraunhofer ISI innovation system approach. After an intense debate we came to the conclusion that this is not necessary, because the different existing approaches provide a sufficient analytical basis and have to be used in a flexible and adapted manner.

One aspect in this respect is the combination of the classical approach with the new multi-level perspective when analytically necessary, depending on the objectives of the analysis. If institutions and organisations at different levels (national, regional, sectoral, technological) are the focus of a (comparative) analysis for which a common framework is necessary, and if an overall political context is to be identified and analysed, then the classical model is a worthwhile choice. If, however, the understanding of socio-technical frameworks, functions, interrelations and dynamics in a specific sector or technology is at the centre of analysis, then the new multi-level perspective approach can provide deep insights into the systemic structures of these sectors or technologies by using systemic modelling techniques. In a more static perspective, landscape, regime and niche can be organisationally described using the different systemic elements of the classical approach. It therefore depends on the research objectives, available data and policy orientation of the analysis whether the classical or the multi-level approach or a combination of the two is an appropriate choice. In the context of the research spectrum of Fraunhofer ISI, both approaches are valuable starting points for innovation system analyses and the application of different qualitative methods and qualitative econometric models and the modelling of dynamic processes in complex systems.

Besides these more general conclusions, research regarding the innovation system concept at Fraunhofer ISI is centred on the following aspects:

- *Theoretical foundation and further development*: Research topics include the simulation of transition management or the implications resulting from the dynamics of technology (different maturity levels of technologies) for the requirements and interactions with innovation systems, e.g. with regard to interactions. Other studies address the question of measurement at different spatial levels and the necessary indicator models in relation with data availability. The public governance of innovation and theoretical considerations about instruments that can be designed to implement mission-oriented approaches are other research fields in this respect.
- *Indicators*: The focus here is on bibliometrics, patent indicators, the use of other innovation indicators, benchmarking, mapping, scenarios and foresight, as well as qualitative surveys. The analysis of interactions usually refers to research-led interactions (co-patents, co-publications, network-analysis) as well as financial and product flows (foreign trade) between countries.
- *Modelling*: This aspect is partly connected to the theoretical foundations. Research is done in the context of system dynamics models. One aspect is

modelling the effects of policy measures in order to identify starting points for the evaluation of specific policy instruments in specific technology areas. Modelling an innovation system would be an ideal case (but probably only partially realisable) in order to identify various levers for the optimisation of an output by a given input (or vice versa).
- *Actors*: The innovation system concept as well as many studies conducted by Fraunhofer ISI are R&D-driven. Further development is needed regarding the implications of innovations with little or no formal R&D for the innovation system concept and interactions in the system. Additionally, a differentiation between research and development would be analytically useful. The innovation system concept is industry-oriented and needs to be extended to include innovation in the service sector.
- *Governance*: As a consequence of the given structures in the innovation system heuristics, the policy recommendations do not differ widely. Improvements are needed, for example, in linking innovation and industrial policy (and their instruments). One approach might be to look at the logic of action of actor groups whose cooperative behaviour can be influenced by industrial policy instruments in order to meet specific innovation policy objectives.

In this respect, different approaches and perspectives in innovation system studies by Fraunhofer ISI are presented in the following chapters. *Conceptual and methodological issues* are addressed in the contribution by Jonathan Köhler, Michaela Gigli, Antje Bierwisch and Arne Lüllmann about "New Directions in Numerical Modelling of innovation: Applying agent-based methods and complexity to sustainability transitions" and by Oliver Som in "Innovation systems without formal R&D". The *national perspective* is taken by Rainer Frietsch and Torben Schubert in their contribution "Public research in Germany – Continuity and change" and by Kerstin Cuhls, who looks at Japan 25 years after the study by Chris Freeman in the chapter "The Japanese innovation system 2011 revisited". Other perspectives are analysed in the rest of the contributions. The *technological perspective* is addressed in the contribution by Carsten Gandenberger and Christian Sartorius about "Decentral wastewater infrastructure – Characterisation and overcoming path dependencies based on a technical innovation system analysis" and in the contribution by Antje Bierwisch, Ralph Seitz and Stephan Grandt highlighting "The innovation system of security – A new quality in the relationship between political, economic and social actors". In an *industrial perspective* Emmanuel Muller, Andrea Zenker and Elisabeth Baier focus on the service sector in their contribution about "Knowledge Angels or how creative people foster innovation in the service industry – emerging concepts and international observations". Two contributions highlight the *regional perspective* of innovation. Elisabeth Baier, Henning Kroll, Esther Schricke and Thomas Stahlecker address the discussion about Baden-Württemberg as a production and innovation regime from the 1990s and early 2000s and ask whether the innovation system here is still characterised by path dependency and technological leadership. The cluster concept is integrated in the innovation system debate by the contribution by Thomas Stahlecker, who deals with "Regional clusters and disruptive technologies – The example of the Baden-Württemberg automotive cluster in transition towards e-mobility". Four contributions discuss different aspects of *public governance* in innovation systems: "Challenge-oriented policy-making and innovation systems theory: reconsidering systemic instruments" is the topic of the contribution by Stephanie Daimer, Miriam Hufnagl and Philine Warnke. Timo Leimbach and Sven Wydra raise the question "Friendly or hostile takeover?" and look at the growing entanglement of industry and innovation policies and instruments. A technology policy focus can be found in the contribution by Hans Marth and Barbara Breitschopf titled "Impacts of policy measures on the development and diffusion of micro CHP technology in Germany". The final contribution in this series by Ralf Lindner discusses the "Cross-sectoral coordination of STI-policies: Governance principles to bridge policy-fragmentation".

These contributions constitute a selection of recent research by Fraunhofer ISI and are intended to illustrate that the systemic perspective in innovation research and the use of the innovation system approach, in both the classical and new interpretation, are as alive as they were in 1972 when the Institute was founded.

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