Fraunhofer ISI Discussion Papers *Innovation Systems and Policy Analysis* No. 52

ISSN 1612-1430

Karlsruhe, July 2016

Addressing directionality: Orientation failure and the systems of innovation heuristic. Towards reflexive governance.

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1 Introduction

Since about 15 years, science, technology and innovation (STI) policies are increasingly geared towards addressing objectives reaching beyond an immediate economic focus on growth and competitiveness. This "normative turn" (Daimer et al. 2012) is expressed in the strategic reorientation of national and supranational STI policies to address the so-called ‘grand challenges’ (Kallerud et al. 2013). Well known examples for this ongoing paradigm shift are the European Union's Europe 2020 strategy, the US Strategy for American Innovation or Germany's Hightech Strategy. What is more, the quest to address ‘grand challenges’ such as health, demographic change, wellbeing and sustainability by the means of research and innovation is complemented by and propelled forward by the emerging discourse on responsible (research and) innovation.[1] In essence, RRI aims at improving the alignment of the impacts of technology and innovation with societal demands and values as far as possible. The concept is inherently characterised by a high degree of normativity in order to provide necessary guidance as to what constitutes desired or ‘responsible’ research and innovation (Randles et al. 2014; Lindner and Kuhlmann 2016). The prominent position of RRI in the European Union's research and innovation programme 'Horizon 2020' and the endorsement of the "Rome Declaration on RRI in Europe" by the European Council in 2014 indicate that RRI is increasingly developing relevance for policy, research funding and scientific communities.

Arguably, the articulation and growing relevance of normative directions of research, technology development and innovation in addition to and beyond the objectives of economic growth and international competitiveness signify a paradigm-shift in STI policy. While this reorientation towards addressing challenges, which can be empirically observed, might be welcomed from a normative point of view, it poses significant challenges for the substance, procedural design and coordination of STI. Since the late 1990s, the systems of innovation approach (cf. Edquist 1997; 2005) has established itself as the most influential paradigm within the international innovation research communities. The systems of innovation perspective does not only frame the scientific debates dealing with innovation, it also provides conceptual orientation and strategic guidance for many governments and international and supranational organisations such as the OECD and the European Union (Fagerberg and Verspagen 2009; Lindner 2012).

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1 For the purpose of this paper, the concepts “Responsible Innovation” and “Responsible Research and Innovation” with its acronym RRI will be used interchangeably. For a discussion of the different understandings and applications cf. Tancoigne et al. (2016).

However, in view of the observed normative turn in STI policy, the innovation system heuristic is increasingly being criticized for its inability to incorporate the dimension of normative direction and/or the lack of openness to address objectives beyond systemic imperfections (Daimer et al. 2012; Weber and Rohracher 2012). The innovation system approach has mainly focused on the explanation of (cross-national) differences in the innovation performance of national/technological/sectoral systems by factors outside of the neoclassical framework (Lundvall 1992; Nelson 1993; Sharif 2006). In the course of further developments, market failure as the predominant policy rationale of the time and the chief justification for policy intervention was complemented by the system failure rationale, which takes into account shortcomings such as infrastructural failures, capability and learning failures, transition failures, network failures or institutional failures (Woolhtuis et al. 2005; Chaminade and Edquist 2006; Gassler et al. 2006). Consequently, the innovation system approach is applied with the aim to analyse and tackle structural issues of an innovation system as a means to foster competitiveness, economic growth and employment. So far, the innovation system heuristic neither provides sufficient analytical nor conceptual orientation for questions related to fostering innovation towards certain ends in addition to and/or beyond the narrow economic growth paradigm (Quitzow 2011; Bajmócy and Gébert 2014). As a result, established practices and institutions continue to operate with the chief aim of improving innovation capacities by "getting the structures right", thereby sidestepping the question "getting the structures right to achieve what?".

However, despite the fact that the innovation system approach and its numerous variants have frequently been criticised for, among other weaknesses, their one-dimensional focus on economic development, the tendency to overemphasize technological innovation and implicit mechanistic notions (Soete et al. 2010; Dodgson et al. 2011; Mahroum 2012), we claim that the heuristic itself continues to provide useful analytical lenses and constitutes a valuable conceptual frame of reference for the design of STI policy. Most notably and well established within the STI community, the emphasis of the innovation system approach on interactivity and interdependence between different actors, the understanding of innovation as a collective endeavour which is influenced by complex framework conditions, the awareness about the roles of different sources of innovation (e.g. non-R&D activities) and the prominent position of reciprocal learning processes as chief drivers of innovation remain important guideposts (Metcalf 2003; Soete et al. 2010).

Given these valuable analytical qualities, the question is raised how the innovation system approach should be revised and developed further in order to respond to the challenges of directionality and normative orientation.

Reflexive innovation systems

As an answer to this question, we propose to introduce a set of conceptual elements with the objective of enabling the systems of innovation heuristic to incorporate requirements of directionality and normative orientation. These four elements, constituting what we term *reflexive governance*, are conceptualised as quality criteria of innovation systems – understood as ensembles of all relevant institutions and actors involved in the development, diffusion and use of innovation (Edquist 2005: 182; Kuhlmann et al. 2010: 3; Warnke et al. 2016: 2). These quality criteria shall help to identify, assess and ultimately guide innovation processes towards desired directions. The four capacities for reflexive governance of innovation systems are:

- Self-reflection capacities,
- Bridging and integration capacities,
- Anticipation capacities, and
- Experimentation capacities.

Section 3 presents the four capacities in detail, and demonstrates how they relate to the three stages of 'directional' innovation processes – situation analysis, goal formulation and specification, and implementation – which we differentiate for analytical purposes. In fact, 'directional' innovation processes are not assumed to be more linear than 'undirected' innovation paths, but the difference is that the concept of reflexive governance makes the steps of situation analysis and goal formulation/specification explicit and required parts of the process. The definition of the situation and the formulation of goals (hitherto growth and competitiveness) are thus internalized and no longer exogenous to the innovation system.

The term reflexivity was chosen to characterise the proposed quality criteria as they essentially attend to an innovation system's collective ability to reflect about a given situation, to deliberatively define the goals of innovation and eventually to transpose these into strategy. Applying the concept of governance in the context of the systems of innovation heuristic is uncommon. Even so, we suggest to introduce the notion of governance, understood as the intentional interaction and coordination of state and non-state actors with the aim to influence innovation systems (Borrás and Edler 2014: 14), in order to conceptually capture actors' purposeful attempts to change decisions and decision-making processes, framework conditions and STI processes towards certain ends (or to prevent such change).

To recapitulate, our points of departure for this proposition are (1) the observation of a conceptual 'blind spot' in the established systems of innovation heuristic. While the systems of innovation approach primarily serves to identify relevant system elements

and supports the analysis of the interplay of interaction and knowledge exchange, it fails to provide conceptual underpinnings on the requirements for an innovation system to identify, assess and ultimately instigate actions with the aim of guiding innovation towards desired directions. This deficit might also be termed as the 'governance gap' of the conventional systems of innovation approach. (2) Contemporary literature on the governance of STI provides a rich reservoir of approaches, instruments and mechanisms on how to steer, influence or 'nudge' actors and institutions with the specific aim of modulating and orchestrating innovation trajectories according to desired ends. Hence, we propose to systematically integrate a dedicated governance perspective into the systems of innovation heuristic in order to address the identified orientation failure. To a large extent, the rise of the analytical term ‘governance’ since the 1980s is a reaction to the perception of the state's weakening capacity to effectively steer, and to the growing interdependence between societal subsystems such as different policy areas and communities or different functional areas. As growing interdependencies in general mean increasing complexity of policy and politics, this implies that cooperation and coordination between different actors become progressively more important (Jessop 2003: 103). Given the highly complex nature of the grand societal challenges, which require far-reaching socio-economic transformation if they are to be adequately addressed (Kuhlmann and Rip 2014; OECD 2015), governance approaches suggest themselves as a potentially useful contribution when dealing with complex actor constellations and their interplay.

The rationale for introducing the element of reflexivity in the re-conceptualisation of the systems of innovation approach, operationalised as a set of four capacities, is twofold. First and most obvious, a conceptual vehicle was sought to integrate substantial issues (normative direction, problem-/solution-orientation, policy goals, missions etc.) in systems of innovation thinking. To this end, the governance perspective with its analytical focus on actors' intentionality to influence innovation and its fittingness to cope with interdependencies was proposed. Second, such a rather technocratic approach is prone to advance or at least assert top-down prescriptions which normative directions an innovation system should take. ‘Grand challenges’, missions or similar broad and far-reaching substantive goals and related implementation measures are likely to face low acceptance and will ultimately suffer under weak legitimacy when they are not well-grounded in broad-based processes of collective sense-making, deliberation and negotiation. Thus, we propose to *endogenise* the processes of defining and concretising normative directions and their implementation within an innovation system. While the broad objectives and directions to take remain to be set through formally legitimised representative-democratic decision-making routines, the STI actors need to be adequately involved in the concretisation of directions and the definition of socio-technical

pathways. In order to achieve this, innovation systems require reflexive capacities and appropriate governance mechanisms.

In addition to the objective of addressing orientation failure, the emphasis on reflexive capacities in the systems of innovation framework also resonates with and responds to a number of interrelated phenomena and developments observed by contemporary innovation research:

- As Warnke et al. (2016) convincingly show, the actor landscape in innovation systems has become significantly more diverse compared to the established understanding reflected in systems of innovation literature, calling for a broadened view of the relevant actors as well as a revision of their relationships and the functions assigned to them.
- Closely related to the appearance of new actors in innovation systems, new types of innovation, such as user-driven innovation (von Hippel 2005), social innovation (Moulaert et al. 2013) or forms of collaborative innovation (Warnke et al. 2016: 10 ff.), are increasingly recognised as relevant, thus changing the dynamics of innovation systems accordingly.
- Science-society relations are shifting, indicated by changing expectations of society towards science and research concerning contributions to societal challenges and value-orientation. Moreover, knowledge availability and science-literacy have increased, empowering parts of the citizenry to critically assess and proficiently question science and research.
- STI and related policy are facing increased pressures to legitimise their actions and outcomes, calling for more transparency and higher levels of readiness of scientists and researchers to engage with and respond to stakeholders and lay people.
- The increasing influence of societal missions and challenge-oriented research has sparked debates about the status of academic freedom and scientific autonomy. Arguably, the collective processes of goal formulation in reflexive innovation systems have the potential to regain some influence for research and innovation actors concerning which directions to take, when they are acting with an outward-looking perspective. And in a reflexive innovation system, the balance between investigator-governed research and mission-governed research (Arnold and Giarracca 2012) should be subject to deliberate social choice.
- Participatory approaches and particularly upstream engagement as important approaches to social control of technology have received much attention in STI policy discourse (Wilsdon and Willis 2004; Fisher et al. 2006). However, they have also received criticism for implicit notions of linearity, technology determinism and their vulnerability to instrumental use (Stirling 2008: 264). The proposed reflexive capacities, which reach beyond participatory mechanisms, address all phases of the innovation process and deliberately incorporate processes of deliberation, experimentation and also policy or "strategic intelligence" (Kuhlmann et al. 1999). They can also be un-

derstood as an attempt to breakup these confines and avoid prematurely closing down the possible range of technological choice (Stirling 2008). This connects to the STS literature and its Social Construction of Technology framework. If technology is socially ‘constructed’, then the goals and norms of society will necessarily play a role.

Based on the considerations outlined in this introduction, we propose that *reflexivity* or *reflective capacities* should be major criteria of the quality of innovation systems. The ability of innovation systems to collectively reflect about orientation and objectives, and to bring together actors to deliberate goals, to prioritize and to specify them should enter the systems of innovation concept as quality criteria in addition to the system functionalities currently primarily endorsed by the concept. Taken together, the reflexive capacities constitute an additional 'reflexivity layer' in the innovation system, and functions as a framework condition similar to the socio-cultural context of a system (see also section 3.3).

In the following section 2, the development of the main strands of the systems of innovation literature will be discussed and complemented with the key insights of contemporary debates related to the ‘grand challenges’ and the governance of STI. In section 3, our proposition to revise the systems of innovation approach by incorporating reflexivity and associated quality criteria is presented in detail. The final section 4 discusses the conceptual contribution and draws conclusions for STI analysis and policy.

2 Conceptual foundations for a revised systems of innovation heuristic

2.1 Systems of innovation approaches and first steps towards re-conceptualisation

As briefly outlined above, the systems of innovation heuristic (Lundvall 1992; Nelson 1993; Edquist 1997) continues to be the most influential paradigm within the international innovation policy community. In systems of innovation thinking, innovation is conceptualised as a nonlinear, evolutionary and interactive process characterised by reciprocity and iterative feedback mechanisms, in which actors (e.g. firms), organisations (e.g. universities, customers, government) and institutions (e.g. regulations, culture) interact in many ways. A distinction can be made between national (Freeman 1995; Nelson 1993), regional (Braczyk et al. 1998; Cooke et al. 1997), sectoral (Breschi and Malerba 1997; Malerba 2002) and technological innovation systems (Carlsson 1995; Carlsson and Jacobsson 1997). Particularly the latter has increasingly become a popular concept in analyzing innovation processes concerned with emerging technologies. Technological innovation systems (TIS) are defined as "socio-technical systems focused on the development, diffusion and use of a particular technology (in terms of knowledge, product or both)" (Bergek et al. 2008: 408). The TIS framework consists of different structural elements, such as actors or networks of actors, institutions and the interactions between them (Markard and Truffer 2008; Wieczorek and Hekkert 2012). Next to structural components, the focus on systemic processes (functions) within TIS is a more recent addition to the concept (e.g., Hekkert et al. 2007; Suurs et al. 2009; van Alphen et al. 2010). Hence, within the TIS framework, the structures and functions are usually analyzed on a system level.[2]

Innovation system analysis mainly focuses on the explanation of the economic performance of national/regional/technological/sectoral systems by factors not considered by mainstream neoclassical thinking in economics (Sharif 2006). The predominant policy rationale of market failure has been complemented by the system failure concept, which takes into account weaknesses such as infrastructural failures, capability and learning failures, transition failures, network failures (weak and strong) or institutional failures (Woolthuis et al. 2005; Chaminade and Edquist, 2006). Thus, the systems of innovation approach is usually applied as an alternative to the neoclassical approach

2 The literature usually operates with seven key systems functions which technological innovation systems need to fulfil: 1. entrepreneurial experimentation, 2. knowledge development, 3. knowledge exchange, 4. guidance of the search, 5. formation of markets, 6. mobilization of resources, and 7. counteracting resistance to change (Hekkert et al. 2007).

with the aim to tackle generic questions of innovation and its role for economic growth and employment. To a large extent, this narrow focus on economic growth and employment has been reinforced by corresponding demands of policy makers. Edquist points out for example: "I assume that the objectives – whichever they are – are already determined in a political process. It should also be mentioned that they do not necessarily have to be of an economic kind. They can also be of a social, environmental, ethical or military kind. They must be specific and unambiguously formulated in relation to the current situation in the country or in other countries. With regard to innovation policy the most common objectives are formulated in terms of economic growth, productivity growth or employment." (2002: 220). Also in Porter's work (1990), the role of policy in directing innovation is mentioned, however this does not refer to strategic priority-setting but rather to standards and regulations. Apart from that, Porter and Nelson (1993) agree in their view that the direction of innovation is a function performed mainly by customers.

However, it has frequently been criticized that innovation system analysis places too much emphasis on the strengthening of generic innovation capabilities and less on certain outcomes (Wydra 2015). As Daimer et al. argue: "Despite all the refined understanding of innovation systems, the instruments derived from the innovation system approach are mainly directed at enhancing the innovation ecosystem in order to strengthen innovation capability. So far, there is no attempt to build on the innovation system heuristic in order to modulate innovation journeys towards certain desirable objectives. So whereas system failure appears to be addressed, 'orientation failure' has largely not been tackled." (2012: 222). Similarly, Quitzow points out: "To date, the systems of innovation approach has largely been employed to tackle generic questions of innovation and its role in economic development. From a policy perspective, research has not focused on understanding how policy might steer innovation in a particular direction (i.e. towards improving the environmental performance of the economy) but on how to strengthen innovation within the economy more generally." (2011: 13).

Criticism has also been raised against the TIS approach. This concept presumes that the diffusion of a pre-defined specific technological solution is desirable from a socio-economic point of view. This perspective has its limits particularly in a long-term perspective, given the complexity and uncertainty of innovation paths. In addition to the problematic ex-ante determination of a technological choice, Truffer points out that "TIS scholars are blamed to reduce transitions to a simple problem of diffusing new and better technologies, whereas the reorientation of user practices, power relationships, regulatory structures, mind sets and public discourses remains unaddressed." (2015: 65).

Mazzucato (2015a, b) arrives at similar conclusions regarding directionality failures in her current work on the role of the state in innovation processes. She points out that markets are "blind" (Nelson and Winter 1982; Dosi 1982) and that the direction of change provided by markets often represents suboptimal outcomes from a societal point of view. Hence, the market failure approach but also the systems of innovation heuristic "cannot explain and justify the kinds of transformative mission-oriented investments that in the past picked directions, coordinated public and private initiatives, built new networks, and drove the entire techno-economic process, which resulted in the creation of new markets, not just in the fixing of existing ones" (2015a: 5). With regard to addressing societal challenges, governments have to lead the process and provide the direction toward new "techno-economic paradigms" (Perez 2002), which do not come about spontaneously out of market forces. Besides referring to the theoretical conception of techno-economic paradigms, Mazzucato underpins her argumentation with the empirical observation that for many technological transformations, governments made direct "mission-oriented" investments in the technologies that enabled these revolutions to emerge (Mazzucato 2015a: 6).

Against the background of these discussions and observations, innovation scholars started to recognize the need to further develop the systems of innovation approach and related innovation policy concepts in order to better address socio-economic goals. Bajmócy and Gébert (2014) combine the systems of innovation approach with the capability approach that has been developed by Amartya Sen. They take the capability approach as a starting point for an alternative to the growth-centred paradigm and examine whether such a shift to well-being as the main policy objective changes the set of information needed for the design, implementation and evaluation of innovation policies. They conclude that the capability approach would broaden the boundaries of innovation system analysis and requires a change in the informational basis. However, the authors do not focus on the operationalisation of such an extended innovation model.

Weber and Rohracher (2012) integrate insights from the systems of innovation approach and a Multi-Level Perspective (MLP) (Geels 2002) in a comprehensive 'failures' framework that includes the focus on societal goals. They claim that the combination of MLP's goal-oriented system transformation approach, complemented by the related approaches of Strategic Niche Management (Kemp et al. 1998) and Transition Management (Rotmans and Loorbach 2006), with structure-oriented systems of innovation approaches improve the conceptual foundation and actual implementation of transformation oriented innovation policies. The authors propose the recognition of additional types of failures next to market and system failures in an innovation (production and consumption) system, the so-called transformational system failures in order to take

into account the requirements of goal-oriented transformative change. Among others, they identify two types of failures that seem to be linked to socio-economic outcome orientation: directionality failure and reflexivity failure. Regarding directionality failure they point "… to the necessity not just to generate innovations as effectively and efficiently as possible, but also to contribute to a particular direction of transformative change. This direction is defined, for instance, by the identification of major societal problems or challenges, for which solutions need to be developed with the help of research and innovation" (Weber and Rohracher 2012: 142).[3] However, different failure mechanism may occur, e.g., the lack of a shared vision regarding the goal and direction of the transformation process or the inability of collective coordination of distributed agents involved in shaping systemic change. Concerning reflexivity failure, they claim that "…a continuous monitoring with respect to progress towards the transformation goals and the development of adaptation strategies" (Weber and Rohracher 2012: 142) is required to address the uncertainty surrounding innovation and change in the transformative process. Potential failure mechanisms may relate e.g. to a lack of distributed reflexive arrangements to connect different discursive spheres, and insufficient spaces for experimentation and learning (Weber and Rohracher 2012).

Apart from these contributions concerning the rationale of innovation policy, a few authors analyze potential implications for governance and policy measures to better achieve such socio-economic goals[4].

Daimer et al. (2012) propose that systems of innovation approaches should incorporate an orientation function as an integral element in order to improve innovation capabilities to address 'grand challenges'. They study the refining of policy instruments towards addressing societal outcomes for two systemic policy instruments, evaluation and foresight. For example, participatory evaluation approaches could be complemented with the analysis of new impact types (e.g. sustainability) or behavioural additionality. Similarly, foresight processes that explore innovation journeys as an element of challenge oriented innovation policy strategies are identified as suitable orientation instruments.

Mahroum (2012) claims that most existing innovation policy tools only address constraints and barriers of innovation linked to broader socio-economic problems, but the policy instruments themselves are not linked to the desired outcome. In order to establish those linkages, he introduces an analytic-diagnostic framework that aims to help develop innovation policies designed to achieve certain socio-economic outcomes. The

3 This line of reasoning may be combined with rationales of other aspects of mission-oriented policy, such as policy coordination etc.

4 The review is based on earlier work of Wydra (2015).

main idea is to start from the desired outcome and deduct (among others) policy rationales and policy instruments. Overall he identifies four categories of outcomes which would be addressed by different interventions (e.g. mission-oriented policies): developing capabilities to meet critical needs in defence, environment and health; broad and diversified capabilities to create higher living standards; generation of new supply chains that would create new value; wide market uptake for specific solutions such as alternative energy products.[5]

To conclude, there have been different contributions to the justification of mission-oriented policies as well as some approaches to develop innovation policies to achieve certain socio-economic outcomes. However, they do not systemically elaborate how the innovation system concept could be modified to be able to analyse orientation capabilities and thus contribute to the avoidance of orientation or outcome failures.

2.2 Grand challenges and mission oriented policies

Regarding policy practice, the notion of 'mission orientation' in STI policy was subject to significant transformations since the mid of the 20th century. Daimer et al. (2012: 218 ff.) outline several paradigm shifts of innovation policy. In the 1960s, the primary goal of innovation policy was to fix 'market failures' by funding basic research. This was followed by several different phases of mission oriented innovation policies that were designed to reach pre-defined goals: After the first phase of 'classic' mission orientation that was mainly characterized by funding schemes such as the US Apollo 1 space program, the second phase that started in the 1980s combined several policy instruments. In this second phase, non-linear, recursive interactions of heterogeneous actors were addressed, however, "policies solely targeted selected sectors and technologies" (Daimer et al. 2012: 219). In the 1990s, innovation policy entered a third phase that was driven by the idea of optimising the 'innovation ecosystem' to improve innovation capabilities with the aim to strengthen competitiveness and economic growth. Policy instruments were targeted at enhancing systems' learning capability, improving the management of interfaces and capacity building among different actors in the innovation system. The application of innovation system thinking and analysis did not necessarily come along with new policy paradigms as they rather complemented already established approaches.

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5 However, he only links broad strategies of innovation policy making to certain goals and does not specify to which extent certain instruments themselves change. Moreover, the possibility that one policy intervention may intend to address several potential goals at the same time is not considered.

Today, the rationales of competitiveness and economic growth have been complemented by additional goals of STI policy that can be summarized as addressing ‘grand challenges’, such as adaption to climate change, health or integrative societies. This transformation of goals beyond a quantitative economic output is what Daimer et al. (2012: 218 f.) call a "normative turn" in innovation policy and related innovation activities. The corresponding idea of a new mission orientation typically combines several characteristics (cf. Dachs et al. 2015: 5 ff.): In order to achieve societal goals, transdisciplinarity, international collaboration, and emphasises a broad dissemination of innovation need to be fostered. Its instruments are open to different competing technologies, and focuses on system innovations that integrate both social and technological innovations. It addresses a wider circle of actors within the innovation system, and is systematically coordinated between different ministries, departments and other public agencies at different levels.

An empirical comparison of today's national innovation policies in different countries (OECD 2014: 110 ff.) reveals significant differences in the realization of this new mission orientation: While many national innovation strategies lack an explicit reference to ‘grand challenges’, most of the other strategies are designed "[…] both to strengthen growth and to address a range of global and social challenges, including climate change and health." (OECD 2014: 94). Table 1 shows all national and supranational innovation policies/strategies that are explicitly related to ‘grand challenges’. The ‘grand challenges’ addressed across these strategies can be attributed either to a societal domain or to sustainability/‘green growth’. Most of these strategies address several ‘grand challenges’ ranging over different domains. Remarkably, they often represent issues that are related to specific characteristics of the respective country. Thus, speaking of ‘*global* grand challenges’ seems exaggerated at this point.

The French National Research Strategy represents an innovation policy that is already quite similar to the idea of a new mission orientation described above: French industrial policies have always been mission-oriented, they were driven for example by military missions, but also by grand societal challenges, such as public health. The current strategic turn was initiated in 2013 by president Hollande and is motivated by an enduring economic crisis and the need for ‘structural’ economic and social reform. Strategy-making involved a forward-looking approach in order to address major transformations under way (ageing, digital revolution, transition to low-carbon economy, metropolisation and more), which call for programming of government action (Pisani-Ferry 2015). Next to the anticipatory approach, the strategy has strong learning and participatory elements.

Table 1: Examples of mission oriented innovation policies; source: OECD (2014)

Country/strategy	Goals/mission orientation
Argentina/Bases for an STI Strategic Plan	Increase consistency and social equality, Promote sustainable development
Brasil/National Strategy for Science, Technology and Innovation (ENCTI)	Promote a green economy; contribute to eradicating poverty and decreasing social and regional inequalities
China/Medium and Long-term National Plan for Science and Technology Development	Build a conservation-minded and environmentally friendly society
Columbia/Sectoral Strategic Plan for Science, Technology and Innovation	Promote knowledge and innovation for production and social transformation
Japan/4th S&T Basic Plan	Comprehensive promotion of S&T and innovation and an issue-driven approach through: integrated development of STI policies to address societal challenges; realisation of a policy to be created and promoted with civil society. Priority areas: environment; energy; health and medical/nursing care; social challenges.
France/National Research Strategy (SNR)	Ten societal challenges are identified, and for each challenge a research strategy is defined; a strategy for large equipment, a limited number of major scientific and technological priorities and some steering rules. The ten challenges: sustainable resource management and adaptation to climate change; safe, effective and clean energy; stimulate industrial revival; health and wellness; food security and demographic challenge; sustainable mobility and urban systems; information society and communication; innovative, integrative and adaptive societies; spatial ambition for Europe; freedom and security for Europe, its citizens and its residents.
South Africa/National Development Plan (NDP): A Vision for 2030	Give South Africa a diversified economic base by extracting more local value from mineral resources, ensuring access to good quality water and alternative sources of energy, identifying new and innovative ways to address poverty, inequality and the burden of disease. Priorities areas: water, power, marine, space and software engineering.
EU28/EU Framework Programme for Research and Innovation – Horizon 2020	Meeting societal challenges: address concerns of citizens in Europe and elsewhere (health and well-being, food security, sustainable agriculture, bioeconomy, secure and clean energy, smart and integrated transport, environment, resource efficiency, inclusive, innovative and secure societies).

2.3 STS – micro level thinking

Science and technology studies (STS) are the study of the processes and outcomes of science and technology. STS is interdisciplinary, including sociology, history, philosophy of science and technology, and anthropology (Sismondo 2010). For the purposes of governance of innovation, we summarise the technology side of STS. It views technology as well as science as social activities. It is non-positivist, in particular, it argues that there is no technological 'method' that can simply be used to apply scientific knowledge to produce technological artefacts.

> "...the interpretations of knowledge and artefacts are complex and various: claims, theories, facts and objects have very different meanings to different audiences." (Sismondo 2010: 11)

Instead, both science and technology are 'constructed' by people in society. Both science and technology are therefore products not only of objective laws, but of their social context. This has led to the idea of Social Construction of Technology (SCOT).

There is little direct consideration of the governance of innovation in the basic introduction to STS in Sismondo (2010). However, science policy is also a result of the insights generated by STS.

This constructivist approach to technology implies that technology is influenced by policy as one part of society, together with other social actors. This then is similar to the innovation systems analysis, but with an emphasis on the sociological aspects of technology – how it plays a role in peoples' lives and how actors understand their use of artefacts to fulfil their needs.

The implication for reflexive governance is quite strong: innovation is a social phenomenon, determined not just by the scientific and empirical knowledge in society, but also by the views and needs of social actors. Governance processes can therefore play a role in determining and realising the direction of innovation, as can the other actors involved in technological development.

2.4 Governance of science, technology and innovation

The debates on governance of STI are largely detached from conceptual developments of the systems of innovation heuristic. However, against the background of the challenges associated with the growing importance of directionality and normativity in STI, governance and its actor perspective are becoming more important as a means of providing orientation, guidance and eventually coordinating/orchestrating the complex processes of societal transformation.

While a broadly shared and uncontroversial definition of governance does not exist, most would agree that the concept refers to the increased role of non-government actors in policy-making (Bache 2003). Most importantly, forms of hierarchical, top-down command-and-control approaches have been increasingly complemented and often supplanted by non-hierarchical forms of decision-making such as negotiation, consultation or dialogue (Jessop 2003: 104). In this sense, governance can be located somewhere between the market's 'invisible hands' and the 'iron fist' of centralised, hierarchical government (Jessop 2003: 101). In an overview of the debate, Grande (2012: 566 f.) identifies five core elements which seem to constitute the core of contemporary understandings of governance: (1) importance of non-hierarchical forms of decision-making; (2) a growing role of non-state actors; (3) growing interdependencies between policy areas and societal subsystems; (4) increasing complexity; and (5) increasing importance of coordination and cooperation.

The rise of the term governance during the last three or four decades is related to a number of interconnected changes in the way contemporary, highly industrialised societies are organised and governed. In essence, governance can be understood as a response to intensified social complexity. According to Scharpf, "the advantages of hierarchical coordination are lost in a world that is characterized by increasingly dense, extended, and rapidly changing patterns of reciprocal interdependence, and by increasingly frequent, but ephemeral, interactions across all types of pre-established boundaries, intra- and interorganizational, intra- and intersectoral, intra- and international" (1994: 37).

However, the increased importance of non-state actors – a development often referred to as "from government to governance" – does not simply result in a diminishing role for government per se. Instead, the changes in the modes of coordination we can observe are not a uniform shift away from government, but represent multiple and intertwined changes between state intervention and societal autonomy in which different forms of rule setting, steering and governing co-exist and interact (Jordan et al. 2005: 484; Mayntz 2009: 105; Lange et al. 2013).

Many definitions of governance are based on the key elements outlined above and thus emphasis – in a variety of combinations and by stressing different aspects – the interactive processes of purposeful coordination and/or management between different (types of collective) actors in coupled and overlapping arenas (cf. Kooiman 1993; Kuhlmann 2001; Jessop 2003; Benz 2006; Voß et al. 2006; Mayntz 2009).

With the aim of making the general governance concept fruitful for our conceptual approach to reflexive innovation systems, we draw on Borrás and Edler (2014) who define governance in relation to STI as the

> "[...] way in which societal and state actors intentionally interact in order to transform ST&I systems, by regulating issues of societal concern, defining processes and direction of how technological artefacts and innovations are produced, and shaping how these are introduced, absorbed, diffused and used within society and economy." (2014: 14).

Two aspects make this definition particularly useful compared to other suggestions. First, Borrás and Edler (2014) provide a definition which specifically refers to research and innovation systems, thereby highlighting the complex processes of co-construction and diffusion. Second and even more important in our context, the definition explicitly addresses actors' purposeful attempts to influence decisions and decision-making processes, framework conditions and STI processes towards certain ends (or to prevent such change). This understanding also underscores the fact that governance more often than not encounters contestation between different problem definitions, goals, and interests.

The topic of reflexivity or reflexive governance is not new in STI-related research. On the contrary, an impressive number of approaches and concepts dealing with questions of societal embedding of technology and innovation, steering socio-technical change, and the integrated assessment of the potential social, economic and ecological impacts of STI have been developed and implemented in the past. To some extent they constitute what might be termed '*de facto* reflexive governance'.[6]

One of these concepts is 'strategic intelligence', understood as a set of sources of information and explorative as well as analytical (theoretical, heuristic, methodological) tools employed to produce 'multi-perspective' insight in the actual or potential costs and effects of public or private policy and management (Kuhlmann et al. 1999). Typically, Technology Assessment (TA), foresight processes, evaluations and the like constitute strategic intelligence and share the objective of contributing to the development of STI strategies by analysing and assessing their broader implications in advance (Ely et al. 2014; Lindner et al. 2016). While strategic intelligence is primarily – but not exclusively – based on expert knowledge and intends to enlighten and rationalise debate and deci-

6 Using the term '*de-facto* reflexive governance' in this context was originally inspired by Rip's (2010) discussion of '*de facto* governance'. Its application was further elaborated by Randles et al. (2016) who refer to governance related to responsible research and innovation.

sion-making, other governance approaches place less emphasis on appraisal and rather focus on the active integration of diverse perspectives and stakeholders in the actual processes of STI. Well-known examples include Constructive TA (Rip et al. 1995), real-time TA (Guston and Sarewitz 2002), mid-stream modulation (Fisher et al. 2006), value-sensitive design (van der Hoven and Manders-Huits 2009) or anticipatory governance (Guston 2014). Most of the rather recent conceptual contributions to the RRI debate follow this line of reasoning by explicitly emphasising reflexivity in the governance of research and innovation (cf. Stilgoe et al. 2013; Kuhlmann et al. 2016).

These *de facto* reflexive governance approaches can be seen as a response to the increasing speed, dynamic and uncertainty of contemporary technology development. The approaches' common objective to modulate STI trajectories in a forward-looking, anticipatory and broad-based manner integrating multiple perspectives is driven by the hope to come to terms with the Collingridge-Dilemma (Collingridge 1980). The fundamental uncertainties we face when dealing with STI is further amplified by the complexity and ambivalence associated with the ‘new missions’ or societal challenges addressed by contemporary STI policy as they require broad systemic transformations encompassing interdependent social, technological, economic and ecological elements.

Against this background, approaches are needed which take into account complexity, uncertainty and ambiguity. Reflexive governance currently seems to be the most appropriate governance mode in the field of STI due to its openness towards alternative solutions and pathways, experimentation and learning. Instead of trying to follow the illusion of complete knowledge and control, reflexive governance fosters continuous reflection and learning while tentatively modulating developments (Voß et al. 2006: 6 f.).

3 Reflexivity of innovation systems

In our understanding, reflexivity of innovation systems means a set of system qualities and processes underpinning the ability to address directionality in innovation. Reflexivity denotes a specific quality of an innovation system, similar as framework conditions such as culture, infrastructure, standards, norms or policies defining the 'rules of the game'. Reflexivity is a 'layer' of an innovation system which is embodied in certain capabilities owned by individual actors in the system, by the organizations (collective actors) in the system, and hence by the system as a whole (see section 3.3). These capabilities are reflected by the attitudes and expressed opinions of individual and collective actors and by the way they organize processes and interactions in the system. To illustrate the abstract concept, we provide dimensions of reflexivity, indicators and examples below.

We propose reflexivity as a response to increasing complexity in innovation because an innovation system with reflexive capabilities is able to better endogenize the directionality question. Reflexive innovation systems, as we conceptualize them, are characterized by the internalization of problem-oriented and strategic thinking into innovation processes, by the ability of actors to debate challenges, to agree which challenges need prioritization and how to concretise their implementation. Thus, reflexivity is an answer to the currently observed normative debate in innovation policy, in which policy objectives beyond immediate economic growth and competitiveness – such as addressing the grand societal challenges of our time – become relevant. This sheds a different light on how innovation systems can perform the ‘guidance of the search’ – one of the seven functions put forward in the context of technological innovation systems (TIS) (cf. section 2.1). TIS-approaches often implicitly assume the ‘guidance of the search’ to be exogenously set by the decision to follow a certain, pre-defined technological path. In contrast, a reflexive ‘guidance of the search’ includes collective strategy processes of the system actors to agree on common goals and to pathways on how to achieve them (and eventually this might mean to pursue multiple (technological) paths in parallel in the beginning when uncertainty about their contributions to reaching the common goals is still high).

3.1 Reflexivity stages and capabilities

How do we make the reflexivity of innovation systems more tangible? How can we detect reflexivity in an innovation system? Or what exactly would be needed to reach higher levels of reflexivity in an innovation system? We have said above that reflexivity means a set of system qualities which are reflected in capabilities, interactions and processes. As such, reflexivity is a quality criterion of the innovation system.

In this section, we define a set of quality criteria of reflexive innovation systems. We have deducted this set of overall ten criteria from literature on innovation systems, in particular on systemic instruments, on the governance of STI, and based on insights from sustainability transition literature. This set of quality criteria shall help to implement our concept in the empirical study of innovation systems as the individual quality criteria can be directly linked to functional units, organizations, and/or policy instruments in the system.

We have argued that the innovation system heuristic needs a governance perspective, and that the governance of an innovation system should serve to direct the system. In order to allow for system-internal strategy formulation and implementation, substantial orientation of the system needs to be endogenized. In their book "Reflexive Governance", Voß et al. (2006) differentiate between two meanings of reflexivity. Our understanding of reflexivity is very much the same in what they term "second order reflexivity" – a conscious and strategic way of decision-making and action (2006: 6).

Furthermore, the authors of "Reflexive Governance" define "strategy elements" of reflexive governance and locate these along the stages of "system analysis", "goal formulation" and "strategy development and implementation" (Voß et al. 2006: 18). These stages are consistent with what we argue are the most pressing needs of innovation systems: A conscious view on system outputs and the kind of directions they serve, as well as the ability to communicate about goals, priorities and strategies within the system. Consequently, the stages "system analysis", "goal formulation" and "strategy development" help to ‘politicize’ the innovation system. Instead of keeping overarching objectives (be it economic growth by way of strong innovation output or the reference to grand societal challenges as defined by policy) exogenous to the innovation system, these stages help to internalize related debate. This is important because the overall strategic orientation of the system is an essential framework condition of all system activities. In order to avoid 'window dressing' of system outputs, understood as a simple 're-labeling' of outputs in the language of an overarching strategy, the actors in the system should be committed to the overall strategy. This is less likely if strategy development is external to the system. Thus, the actors in the innovation system should be able to participate in the making of the strategy. However, the governance of innovation systems should not be misunderstood as a "self-steering of society" (Voß et al. 2006: 8), but as something in which democratic policy-making of representative systems plays a central role. These reflexive elements, which allow for participation and interaction of the actors performing research and innovation as well as user groups, are complementary to policy-making processes in representative political systems – and not a replacement. Or phrased differently, our approach calls for an enhanced role for gov-

ernment to engage in actively shaping and supporting the political and cultural project of socio-technical transformation (OECD 2015).

The three stages **of reflexivity,** where these actors need to act and interact, are (own compilation based on Voß et al. 2006: 18):

- *System analysis* – defined as the identification of needs, demands, values, actors, structures and trends.
- *Goal formulation* – defined as the definition of interests, positions, goals and visions. We adjust the definition of this stage and call it *goal formulation and specification*. This underlines the need that goals should not only be fixed in general terms (e.g. sustainability) but most often require further specification.
- *Strategy development and implementation* – defined as the making of a joint strategy and instruments for its implementation and evaluation.

Given the richness in the literature on reflexive governance elements, we identify and define four types of reflexivity capacities of innovation systems. In the list below, we show how we combine the various sources in the literature into our scheme of capacities. The most important sources are Voß et al. (2006) who talk about strategy elements of reflexive governance, and Weber and Rohracher (2012) who list capacities which are missing in the innovation system. They group these (missing) capacities into four types of failures: reflexivity failures, directionality failures, demand articulation failures and policy coordination failures. As our concept of reflexivity is defined broader, we view all of these capabilities relevant and include them in the list below.

So far we have spoken of system qualities, but most of these criteria cannot be measured directly at a system level. While some criteria require central (governmental) processes or instruments, many others should be present as cultural, structural or procedural elements in the organizations performing research and innovation as well as in stakeholder groups. Here it becomes evident why the reflexive innovation system concept is in need of a governance perspective as it entails a dedicated conceptual approach to the actors in the system. This is needed to understand the actors – be it individual or collective ones – not as functional units, but as acting ones, based on their values, goals and strategies.

Four capacities of reflexivity:

- *Self-reflection capacities*: These can mainly be found at the level of (individual or collective) actors. They include the critical reflection about values and orientation (cf. "value debate" in Daimer et al. 2012: 181), "demand-articulating competencies" (Weber and Rohracher 2012: 1045), as well as the ability to adapt own positions and goals.

- *Bridging and integration capacities*: Here, we distinguish between capacities at actor level and capacities at system level. At actor level, bridging and integration capacities are the (individual) ability (or organizational culture) to think and work transdisciplinary, the openness for different and new knowledge sources, and conflict recognition and moderation. At system level, bridging and integration capacities can be found in "arrangements to connect different discursive spheres" (Weber and Rohracher 2012: 1045), in "joint learning processes between technological AND societal innovators" or "bi-directional" stakeholder participation (Daimer et al. 2012: 177, 180), in processes or structures that allow for "participatory goal formulation" (Voß et al. 2006). A "shared vision regarding the goal and direction of the transformation process" (Weber and Rohracher 2012: 1045) is desirable, but bridging and integration capacities can also be found in the avoidance of "premature closure on easy fixes and actively bring these conflicts into the open" (Daimer et al. 2012: 181). Further system capacities include the "interactive strategy development" (Voß et al. 2006) or the "collective coordination of distributed agents involved in shaping systemic change", "concerted policy initiatives" (Kuhlmann and Rip 2014) as well as multi-level, horizontal, vertical and temporal "policy coordination" (Weber and Rohracher 2012: 1045).
- *Anticipation capacities*: These capacities are those of (individual or collective) actors as well as of the system itself. They include futures literacy (Miller 2007) which can be the "anticipation of long-term effects" (Voß et al. 2006), the anticipation of transformation (Daimer et al 2012: 181; Kuhlmann and Rip 2014) or the ability to deal with uncertainty, e.g. by "adaptive policy portfolios to keep options open" (Weber and Rohracher 2012: 1045). They also include demand literacy, which means "anticipating and learning about user needs to enable the uptake of innovations by users" (Weber and Rohracher 2012: 1045).
- *Experimentation capacities*: Here, we are thinking of collective experiments (Daimer et al. 2012: 181; Joly et al. 2010) and thus phenomena which can be found primarily at system level. We define experimentation as allowing for parallel approaches and learning through failure on all levels and in different contexts. The need for experimentation has also been highlighted by others, e.g. Voß et al. (2006: 433 f.) call for "Experimentation and adaptivity of strategies", Weber and Rohracher (2012) for "spaces for experimentation and learning" and Kuhlmann and Rip (2014) for "tentative policy mixes". In 2008, the Lisbon Expert Group arrived at the conclusion that formats such as OMC-Nets[7], ERA-Nets[8] and Technology Platforms[9] provide a good basis for policy experimentation at the European level, and they should be therefore continued (European Commission 2008: 11).

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7 Acronym for Open Method of Coordination. For more information on OMC-Nets see: http://ec.europa.eu/invest-in-research/coordination/coordination02_en.htm

8 Acronym for European Research Area. For more information on ERA-Nets see http://ec.europa.eu/research/era/era-net_en.html

9 For more information see http://ec.europa.eu/research/innovation-union/index_en.cfm?pg=etp

3.2 Ten quality criteria for reflexive innovation systems

We argue that these capacities should be present in all three stages. In all stages it will be necessary that actors are at the same time self-reflexive and able to anticipate the values and interests of others, and there should be the capacities to deal with uncertainties of the present and the future and to react to them. Obviously, some of these capacities seem to have a 'natural' relationship to some of the stages, for example in the stage of system analysis self-reflection capacities and anticipation capacities play a central role. In the stage of strategy development and implementation, certainly bridging and integration capacities will help to sustain collective coordination, democratic decision-making and joint action.

Nevertheless, in this conceptual step, we relate the four capacities in a matrix structure to the three stages (see Table 2) in order to arrive at a model for further discussion. In this 3x4 matrix, we identify ten relevant relationships which appear to be distinct. There are no 'blind' cells with impossible combinations, but we merge the three stages into one in the case of experimentation capacities as this reflects best the understanding of experiments as learning at all stages and on all levels.

As a result, we define ten quality criteria for reflexive innovation systems which are described below including illustrative examples of relevant actors and/or policy instruments as well as suitable indicators for measuring the presence of these reflexivity aspects. We are convinced that only the empirical application of this matrix can reveal further insights regarding the relative relevance of the cells. Empirical discussion will show which of these cells are needed in order to qualify an innovation system as ‘reflexive’. We assume that some of these quality features will appear to be very important for the system, so they might be identified as obligatory quality features. Others might appear as second-order features which exist in companionship with other features. The ten quality criteria for reflexive innovation systems are:

(1) Self-reflection capacities in situation analysis

The central questions are: Do the actors critically reflect their own situation? Are they aware of their values and orientations? And do they consider other actors' situation, values and positions? The actors in the focus of this analysis should be the relevant stakeholders in the innovation system of interest. In most cases, these will be organizations. Potential indicators to measure this level of self-reflection are content analyses of position papers.

(2) Self-reflection capacities in goal formulation and specification

Central questions are: Are goals formulated at all? Do actors show the capacity to reflect about their goals and to articulate them? Have actors taken up general, overarching goals and specified them to their situation (e.g., "how we can contribute to sustainability")? To what extent are the goals adaptive to their environment, e.g. changing framework conditions or other actors' goals? The actors in focus are mainly the same as in the first cell. However, one can also look at this at system level and ask whether there is a system-wide process to reflect about goals or whether system-wide goals have been explicitly formulated. Potential indicators are position papers (as in the first cell), and organizational mission and vision statements. We might also find goal formulation as the first step of (system-wide) strategy and agenda processes.

(3) Self-reflection capacities in strategy development and implementation

Although there is a logical link to at least cell no. 2, the central questions here are: Is a strategy explicitly developed? Are the goals reflected/applied in the strategy? How does the strategy address its environment, i.e. the framework conditions? Is the strategy resulting from a reflection/learning process? To what extent is the strategy implemented? Are the success and suitability of the strategy evaluated on a regular basis? Is the strategy adapted accordingly, if necessary, in other words, do the actors learn along the pathway? Again, the units of analysis can be the actors in the system or the system as a whole. Potential indicators are strategy processes and papers, agenda processes and their outcomes, or formative policy evaluation.

(4) Bridging and integration capacities in situation analysis

Bridging and integration capacities in situation analysis can be analyzed at actor-level and at system-level. Central questions in situation analysis are: Which knowledge sources are being used or integrated? Do they reflect different types of knowledge, different academic traditions and other knowledge sources? Are different points of view accepted? These might serve as indicators: diversity of members in review panels, task forces or expert groups, 'new' members in such groups beyond the 'usual' suspects; communication style in debates: more 'arguing' than 'bargaining' as an indicator for high bridging and integration capacities.

(5) Bridging and integration capacities in goal formulation and specification

Here, the central questions are: Who participates in goal formulation and specification? And how is the diversity of interests and goals of the actors addressed – in particular at the system-level, where consensus cannot be expected? Do we find conflict recognition and moderation at this stage? Potential indicators are certain process characteris-

tics of goal formulation: Existence of participatory agenda-setting, critical reflection on power imbalances, and the degree of inclusiveness.

(6) Bridging and integration capacities in strategy development and implementation

For the stages of strategy development and implementation, similar process features are needed as in the case for goal formulation and specification. Quality criteria of this stage are: Are strategy processes interactive? Is strategy-making and implementation coordinated across relevant actors? Potential indicators are similar process indicators as in cell no. 5: Heterogeneity of actors involved, coordination across silos, as well as bottom-up and top-down elements for strategy development.

(7) Anticipation capacities in situation analysis

Central questions to analyze anticipation capacities are: Are the actors aware of potential future developments? Which uncertainties do they recognize? How do they deal with them? This can be a quality at actor-level as well as at system-level. Indicators to look at are: Use of forward-looking techniques such as foresight, radars and scenarios. We should also look for evidence of this quality in communications and publications.

(8) Anticipation capacities in goal formulation and specification

A central question is whether "futures literacy" is also present in the stage of goal formulation or specification: Do we find openness towards goals for alternative futures? Does the goal formulation recognize potential uncertainties? Are existing goals reconsidered in light of alternative future developments? This quality is present if goals do not confirm present routines, but help to overcome potential lock-in. Potential indicators – in particular at actor level – are: Existence of processes to break organizational lock-in or to open mindsets beyond daily operational work (e.g. transition management, horizon scanning).

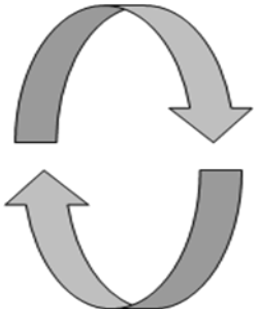
(9) Anticipation capacities in strategy development and implementation

At the stage of strategy development and implementation, similar questions are central: Are strategies adaptive and robust in light of the identified uncertainties and potential (unintended) side-effects? And is the use of anticipation capacities systematic, i.e. do we find a foresight culture? Potential indicators are the existence of systematic use of foresight and systematic assessments of the environment (e.g. environmental scanning (360°)).

(10) Experimentation capacities in all stages

Central focuses of analysis are experimentation capacities and actual examples of experiments: Are experiments used to integrate new actors or new goals or to overcome a lock-in of the system? Is the implementation of parallel approaches allowed for, fostered and accepted? Potential indicators are new formats for discussion or coordination, or new instruments as an alternative to established ones. An important feature of such new formats and instruments is that they support a constant learning process, e.g. a continuous questioning of values, goals and approaches and a search for (parallel) alternative approaches.

Table 2: Quality criteria of reflexive innovation systems

	Self-reflection capacities	**Bridging and integration capacities**	**Anticipation capacities**	**Experimentation capacities**
Situation analysis	Critical reflexion about values and orientation. (1) *Indicators: position papers*	Transdisciplinarity, collective intelligence (4) *Indicators: more arguing than bargaining; diversity of stakeholders, new actors*	Futures awareness, recognition of uncertainties (7) *Indicators: reflected in communications and publications; processes dealing with uncertainty (scenarios, radars, foresight)*	Learning through failure on all levels and in different contexts Allowing for parallel approaches  (10) *Indicators:* *Experimental practices*
Goal formulation and specification	Articulation, adaptation - On both levels – individual and systems level (2) *Indicators: organizational mission and vision statements, system-wide agendas..*	Participatory goal formulation, conflict recognition and moderation (5) *Indicators: Existence of participatory agenda-setting; critical reflection on power imbalances, degree of inclusiveness*	Openness towards goals for alternative futures (8) *Indicators: Existence of processes to break organizational lock-in or to open mindsets beyond daily operational work, e.g. transition management, horizon scanning*	
Strategy development and implementation	Articulation, adaptation and learning (3) *Indicators: strategy processes and papers, agenda processes and their outcomes; formative policy evaluation*	Interactivity and coordination (6) *Indicators: Heterogeneity of actors involved, coordination across silos, bottom-up and top-down elements for strategy development*	Awareness of uncertainties, assessment of (non-intended) side-effects (9) *Indicators: Existence of systematic scanning and assessments (environmental scanning (360°)), foresight cultures.*	

Sources: Own compilation, integrating insights from Voß et al. (2006), Weber and Rohracher (2012), Daimer et al. (2012), Kuhlmann and Rip (2014).

3.3 A revised heuristic of innovation systems

Introducing governance thinking into the innovation system heuristic opens up a new analytical focus on innovation systems which we have elaborated in the previous section. The proposed concept of reflexive governance is a set of ten quality criteria of innovation systems. As such it is also compatible with the descriptive heuristic of innovation systems. We argue that reflexivity is a quality of innovation systems that should be present similar to other framework conditions of the system, e.g. such as certain cultural characteristics or infrastructure.

Translating this conceptual thinking into a graphical representation was an iterative process during which we drew on existing innovation system frameworks – particularly Kuhlmann and Arnold (2001: 2) – and developed these further by integrating components of reflexivity thinking. Figure 1 shows an intermediate result of this process. The main subsystems of the innovation system are depicted at the centre (political system, education and research, intermediaries, industry, and consumers/producers), whereas relatively stable key factors and basic conditions influencing actors' behaviour and interaction between the subsystems are represented as different layers surrounding the core. In addition to general framework conditions and infrastructure, a new 'reflexivity layer' was introduced.

With the aim of integrating the revision of established innovation system frameworks as proposed by Warnke et al. (2016), we added a reflexivity layer to this innovation system model (see Figure 2). This new way of presenting the innovation system heuristic takes into account several aspects which are also of relevance in our concept: they introduce new actors such as philanthropists, innovation intermediaries or societal actors and they present a more adequate and enriched picture of science-society relations.

Figure 1: Graphical representation of a Reflexive Innovation System (based on Kuhlmann and Arnold 2001: 2, own compilation)

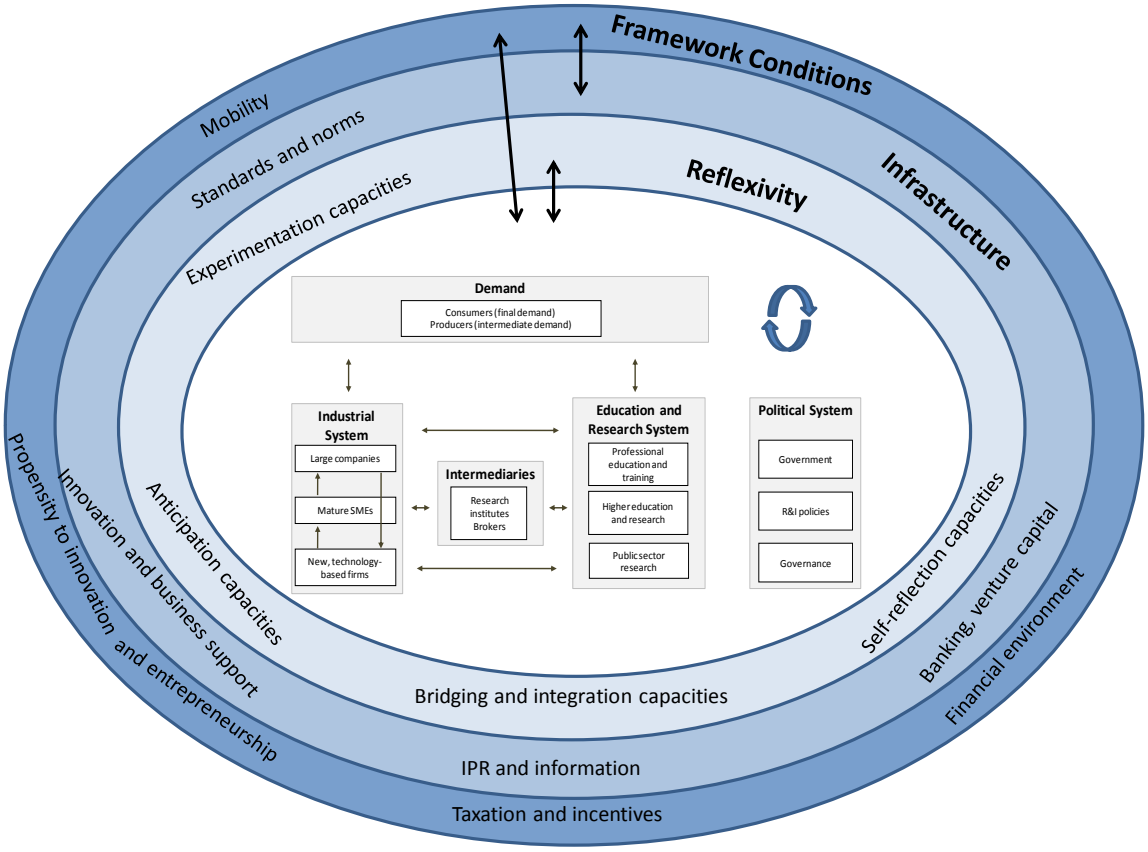
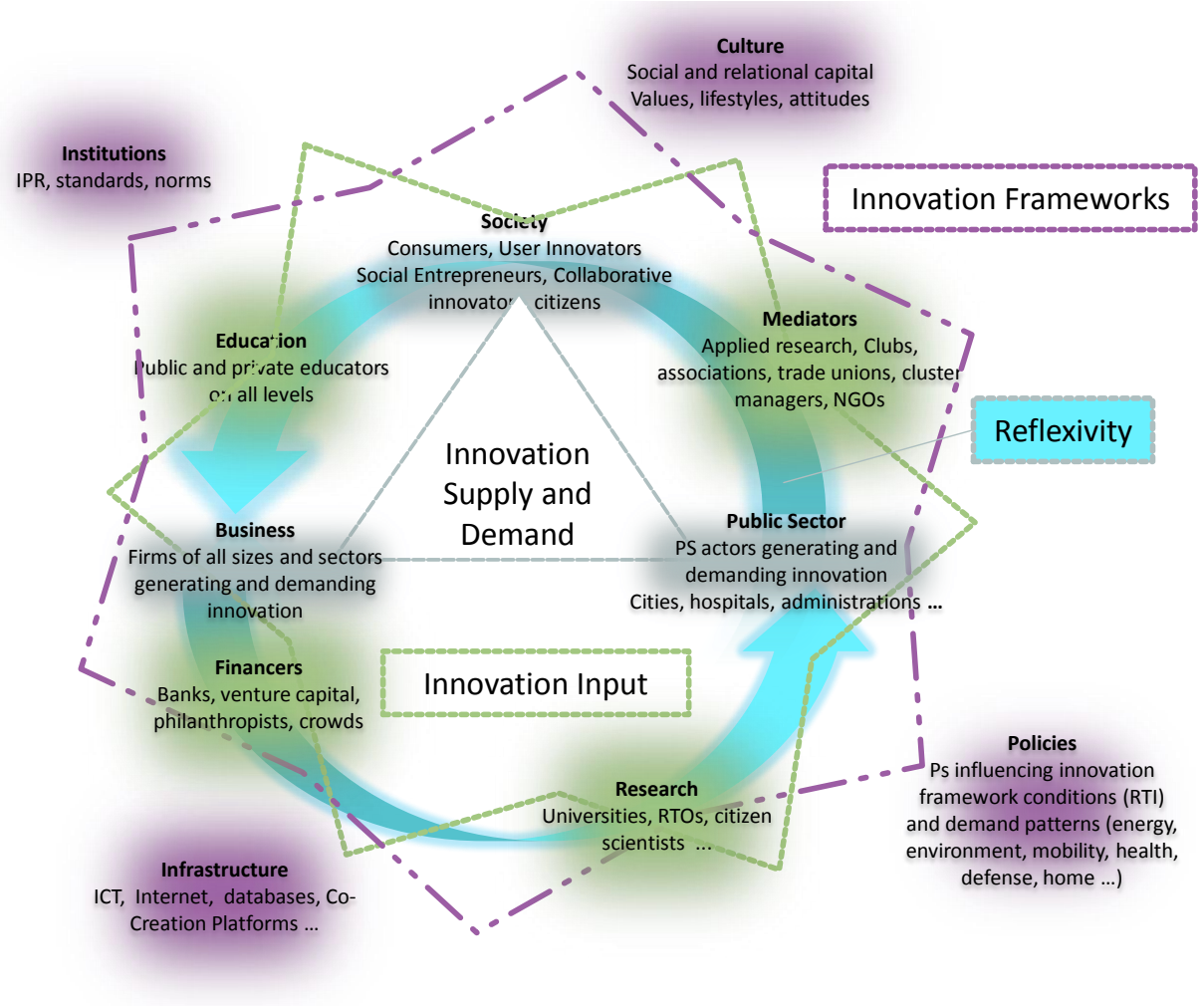


Figure 2: Improved graphical representation of a Reflexive Innovation System (own compilation based on Warnke et al. 2016)



4 Discussion and conclusions for STI research and policy

In this paper we propose to further develop and partly revise the current systems of innovation approach as a response to the inability of this heuristic to convincingly cope with the challenges of directionality and normative orientation in contemporary STI policy. In order to better incorporate the requirements posed by this "normative turn", we introduce a set of four capacities – self-reflection, bridging and integration, anticipation, and experimentation – that signify the capability of innovation systems to guide innovation processes towards desired ends.

Our vantage point is the critical assessment of the narrow economic growth perspective in established systems of innovation approaches. While the systems of innovation heuristic remains a valuable conceptual frame for the analysis and the design of STI policy, it falls short to address issues of directionality and questions which innovations are desirable from a societal perspective. In the recent past, fixing market failures and systemic imperfections as the dominant rationales for economic and innovation policy have increasingly been complemented by new rationales for state intervention and innovation policy (Foray et al. 2012; Mazzucato 2013). Enacting these new rationales or 'missions' requires additional and different approaches than those solely aimed at fostering generic innovation system functions such as interactivity, mutual learning or diffusion. In effect, supporting certain technological trajectories and innovation paths explicitly entails the partial departure from the conventional principle of 'neutrality' (Aghion et al. 2009: 688).

Due to its focus on strategic interaction and on actors' intentionality to influence the quality and direction of innovation processes, the integration of a dedicated governance perspective into the systems of innovation approach is a promising conceptual vehicle to support the identification and assessment of substantive goals, and eventually the guidance of decisions and actions to achieve these ambitions within a given innovation system. Of the rich theoretical and conceptual literature on the governance of STI, we conclude that the literature on reflexive governance is particularly useful in this context. While normative directions for the governance of research and innovation, as widely articulated in missions such as the so-called ‘grand challenges’ and in part promoted by the RRI discourse, are plentiful, these normative directions are – by and large – imposed upon the innovation system actors exogenously, and neither their broad acceptance nor their adequacy are a given. With the aim of increasing the sense of 'ownership', legitimacy and eventually societal robustness, we propose to partly endogenise processes of defining and specifying normative directions. Putting increased emphasis on and improving the capacities of reflexive governance will potentially contribute to the

strengthening of the innovation systems' input-legitimacy. As such, the often criticised preoccupation with output-legitimacy (i.e., the economic performance of innovation systems) can be rebalanced in favour of a stronger focus on the input dimension.[10] Of course, the formal mechanisms of legitimacy in the context of representative democracy remain in place. But in view of the specific characteristics of the STI field such as a high degree of autonomy and self-reliance of the actor landscape together with the substantive openness of research and innovation directions, hierarchical steering and conventional governance settings seem even less suitable in this field than in most other policy areas. Within this setting and in view of the requirements that need to be fulfilled to facilitate innovation systems' self-reflective capacities, to orchestrate the opening-up and closing-down of decision-making processes, and to implement appropriate policy and regulatory measures, the state will have to play a particularly decisive role.

Limitations and future research

We are convinced that the proposed reconceptualisation of the systems of innovation heuristic along the lines of intensified reflexive governance, operationalised by a set of four capacities and related quality criteria, will potentially improve the analysis of innovation systems' ability to address the complex challenges of directionality and, in the long run, also the systems' ability itself. However, while the conceptual development is still in its infancy, we identified a number of limitations and not yet resolved issues which need to be addressed in order to improve both the concept's theoretical underpinnings and its practical use for policy analysis and advice. The most salient points of clarification seem to be:

- We claim that the proposed quality criteria, covered by the respective indicators (Table 2), contribute to the reflexivity of an innovation system. However, at this point it remains an open question, how many and particularly to what extent these criteria should be met in order to signify a 'reflexive' innovation system. We expect that certain criteria are more decisive than others for achieving higher levels of reflexivity in innovation systems, perhaps leading to a hierarchy of first and second order criteria.
- Almost all of the reflexivity criteria relate to both the individual/actor-centred level and the macro/system level. So far, the dynamic interrelationships between these levels are not well understood; moreover, they need to be further specified in terms of the respective indicators. This creates particular challenges for empirical analysis.
- More work needs to be done to identify appropriate, context-sensitive tools, processes and instruments which can be applied by governments to foster the reflexive

10 For a general discussion see e.g. Scharpf 1999, Hurrelmann et al. 2007 and Mayntz (2010: 10 ff.).

capacities of innovation systems. To this end, the diverse contributions from the different disciplines in the social sciences and economics which have been concerned with STI policy and governance represent a valuable reservoir of knowledge.

- Without doubt, enhancing reflexive capacities of innovation systems contributes to the 'opening up' of the wider debate and the related decision-making processes on STI policy. Yet, policy-making routines and factual requirements of programme design, budget-planning, implementation and the like call for policy choices at some point. Thus, the challenge for any reflexive governance arrangement is not only to identify the appropriate scope and the right timing for 'closing down', but to develop institutional conditions for closing down processes that are less prone to be unduly distorted by incumbent interests, power dynamics and strategic framing.
- The proposed revision of conventional systems of innovation thinking aims to be compatible with the different innovation system concepts – i.e., national, regional, sectoral and technological systems of innovation. To which extent this claim can be confirmed needs to be tested.
- We claim that innovation systems with higher degrees of reflexivity are more successful in effectively addressing the challenges of directionality. If, to which extent and how reflexivity influences the performance of an innovation system in this regard will have to be explored empirically.

Most of these open questions and challenges will have to be approached through empirical research. Ideally, a large-scale research programme would need to be devised in which systematic comparative analyses of different innovation systems (national, regional, sectoral, technical) could be conducted. Based on a preliminary and very tentative secondary examination of existing national and sectoral innovation system analyses, we anticipate to identify varieties of reflexivity, depending on factors such as a system's respective institutional make-up, levels of socio-technical and socio-economic development, and cultural variables. Once a sufficient empirical corpus of comparative data is available, a typology of varieties of reflexive innovation systems could be developed.

In many ways, these are exciting times for STI-related research: The debates on 'grand challenges', RRI and questions of directionality open new opportunities and give urgency to researchers committed to innovation system thinking to draw on STS and its understanding of how social and political processes influence innovation trajectories and pathways. At the same time, the complexity of effectively addressing 'grand challenges' opens new connections to and opportunities for exchange with the sustainability research community and their expertise on transitions, and transformative change. The research conducted for this paper is an attempt to contribute to this on-going process of cross-disciplinary collaboration and the underlying paradigm-shifts in STI research and policy.

Acknowledgments

The research for this paper was funded by the Fraunhofer Institute for Systems and Innovation Research ISI. On numerous occasions the authors took advantage of conceptual input and enlightening discussions with our peers in the research community. We are particularly indebted for constructive feedback to Jakob Edler, Susana Borrás, Stefan Kuhlmann, Peter Biegelbauer, Karoline Rogge, Ellen Moors, Annette Braun and many more.

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