Comparing systemic approaches to innovation for sustainability and competitiveness

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Abstract
This paper makes a distinction between three analytical frameworks that have been highly influential in the discourse on innovation, competitiveness and sustainability: sectoral systems of innovation (SSI), technological innovation systems (TIS) and socio-technical systems (including transitions) (STS). These frameworks share a common systemic approach to innovation but are often positioned as different bodies of literature and correspond to different epistemic communities (Fagerberg 2005). The outcome of this paper is explorative and conceptual in nature. This preparatory conceptual undertaking aimed to support the development of an integrated frame for analysis of systemic approaches to innovation and presents a systematic comparative review of SSI, TIS and STS based on predefined dimensions. For doing so, we have made a meta-theoretical comparison of the following dimensions: (1) system boundaries, (2) actors and networks, (3) institutions, (4) knowledge, (5) dynamics, (6) outcome/performance, and (7) methodology. In the concluding section, commonalities, differences, weaknesses and complementarities of the three approaches are highlighted and some preliminary ideas are introduced. Given the exploratory nature of this work, additional research (both at the conceptual and empirical level) of the application of the analytical frame is acknowledged (which it is currently under progress).

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**Introduction**

Sustainability and competitiveness have become of fundamental concern around the world. Both concepts refer to new paradigms of development albeit in different yet related domains. For sustainability and competitiveness alike, innovation is considered a sine qua non. As a result, the emergence of innovation in policy discourses has skyrocketed. Innovation is supposed to mitigate various societal challenges including environmental degradation, competition from low-cost countries, dwindling fossil fuel supplies and social polarisation. This emphasis on innovation has contributed to transcending classical policy boundaries between e.g. industrial policy, environmental policy, science and technology policy (Lundvall and Borras 2005). On the other hand, this popularity runs the risk of degenerating the innovation concept into a meaningless panacea that is supposed to solve all problems at the same time without paying due respect to the nature of the challenges that are raised. A sympathetic yet critical perspective therefore begs the question whether innovation can act as a driver for competitiveness and sustainability simultaneously? To do so, the paper takes stock with the systemic approach to innovation and the set of varieties that have recently emerged in the literature.

This paper makes a distinction between three analytical frameworks that have been highly influential in the discourse on innovation, competitiveness and sustainability: sectoral systems of innovation (SSI), technological innovation systems (TIS) and socio-technical systems (including transitions) (STS). These frameworks share a common systemic approach to innovation but are often positioned as different bodies of literature and correspond to different epistemic communities (Fagerberg 2005). The ultimate

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2 The paper serves as a preparatory conceptual exploration to conduct an analysis of the impact of the Dutch energy transition in terms of sustainability and competitiveness. This policy program seeks to safeguard a sustainable national energy economy. Innovation in renewable energy sources and reduction of energy consumption is regarded as a driving force to achieve the three functional goals to the program: (1) reliable provision of energy services, (2) low prices thanks to economic efficiency and market dynamism, (3) minimal negative environmental and social impacts (Kemp and Loorbach, 2005). To highlight the transcendental character of the program, six ministries work together: Economic Affairs; Housing, Spatial Planning and the Environment; Transport, Public Works and Water Management; Agriculture, Nature Management and Food Quality; Foreign Affairs; and Finance. This policy program is heavily influenced by the work of scholars in the Netherlands on innovation systems, socio-technical systems and transitions (Kemp et al., 1998; Rotmans et al., 2001; Geels, 2002; Geels, 2004; Hekkert et al., 2007).
The objective of this paper is to systematically compare these approaches in order to arrive at insights on which dimensions the respective approaches differ or share commonalities, what their respective strengths and weaknesses are and whether and how they complement each other. A few other scholars have reviewed (a selection of) these concepts (e.g. Liu and White 2001; Chang and Chen 2004; Markard and Truffer 2008). Insights from these contributions are gratefully acknowledged and provide useful input into the following analysis. However, a systematic comparative review of the SSI, TIS and STS concepts based on predefined dimensions has not been conducted previously. More importantly, the paper seeks to arrive at lessons for a more integrated frame for analysis that is able to reconcile the different demands and conditions vis-à-vis innovation from a sustainability and competitiveness rationale. The following paragraph provides an overview of the systems of innovation approach and presents the set of dimensions along which the SSI, TIS and STS concepts subsequently are analysed. This is followed by a paragraph in which these three concepts are introduced and compared. In the conclusion, scope for complementarities across the three approaches is outlined.

A systemic approach to innovation

The innovation concept refers to novel or improved material goods, intangible services or ways of producing goods and services (Edquist 2005). Innovations are iteratively enacted through networks of social relations, rather than through singular events by isolated individuals or organisations. To understand innovation as an inherently social, interactive learning process is probably the defining feature of the systems approach to innovation (Lundvall 1992). Moreover, the innovation system approach acknowledges that certain patterns of interaction are more pronounced than others because organisational behaviour and strategy is shaped (though not wholly determined) by various laws, rules, norms and routines (i.e. institutions). In short, an innovation system is defined as networks of organisations and institutions that develop, diffuse and use innovations (Markard and Truffer 2008). To single out which organisations and institutions are determinants of innovation and in what way, it is common to ex-ante delineate the system boundaries and its components.
There are various ways to specify the innovation system to discriminate between the system and its environment (Bathelt 2003). To carry out empirical research of innovation systems it is crucial to determine what is inside and outside the system. This is necessary to distinguish the endogenous drivers of innovation (those belonging to the system) from the exogenous drivers of innovation (those outside the system). According to Edquist (2005) there are various ways in which boundaries can be drawn: (1) geographically, (2) technological fields, (3) product areas and (4) activities. It is important to consistently consider the boundaries of the innovation system in order to avoid an explosion of possible factors and drivers for innovation. However it would be misleading to purely isolate the system from its environment (Asheim and Coenen 2005). Every system of innovation is situated within a certain context.

According to Edquist (1997) an innovation system is constituted of components of the system and the relations among the components. These components, in turn, refer to organisations and institutions. Liu and White (2001) add to this a qualification between primary and secondary actors. Primary actors are those actors that directly perform innovation activities whereas secondary actors affect the behaviour of or interaction between primary actors. The role of institutions has also been extensively analysed and categorised. The innovation literature is however still highly diffuse and heterogeneous in terms of institutional analysis of innovation systems (Doloreux and Parto 2005; Rohracher et al, 2008). Commonly used and accepted distinctions are those between formal and informal institutions (Edquist and Johnson 1997), regulative, normative and cultural-cognitive types of institutions (Scott 1995), and different levels of institutional structures (Hollingsworth 2000). Institutions often work in a subtle way, as is emphasised by the notion of informal institutions. Habits, conventions and routines regulate social and economic life but being “habitual patterns of behaviour embodying knowledge that is often tacit and skill-like” (Robertson and Langlois 1995) emphasises their often intangible character in contrast to the codified nature of formal institutions. Regulative institutions refer to the formal rules of the game that constrain behaviour and regulate interaction. They determine what is allowed and what is not allowed and are therefore often backed by sanctions. Examples are laws, contracts and norms. Normative
Institutions encompass informal rules that follow from socialisation processes and socially desirable expectations. They confer values, duties, responsibilities, which set out what is right and what is wrong. Cognitive institutions are the rules that “constitute the nature of reality and the frames through which meaning or sense is made” (Geels 2004a, p. 904). Examples are cognitive frames, mental paradigms, visions, expectations, perceptions, etc. The different levels of institutional structures (Hollingsworth 2000, 2000) draw attention to the different aggregation levels by which institutions work. Institutions can be conceptualised as single rules that more or less independently influence social and economic behaviour but also as semi-coherent arrangements that are mutually dependent and exert a specific influence through their interplay.

In an innovation system, knowledge is seen as the most strategic resource and learning as the most fundamental activity (Lundvall 1992; OECD 1997). Despite a general agreement on the validity of this statement, knowledge and learning remain elusive concepts. Based on an extensive literature review Ibert (2007) introduces the perspectives of ‘knowledge’ and ‘knowing’ as representing general intellectual strategies of understanding the peculiar ways human beings know. The former represents the rationalistic approach where knowledge consists of commensurable quanta or discrete entities that share commonalities with a commodity or an economic stock. Being knowledgeable means to ‘possess’ a large number of knowledge entities (Amin and Cohendet 2005). In contrast, ‘knowing’ reverberates an ability to act. It emphasises the collective nature of knowing and it is by default tied to social practice. Therefore knowledgeability stems from different practices which need to be translated across cultural and social boundaries rather than accumulated smoothly. Innovation systems, having been pioneered by the (albeit heterodox) economic disciplines has conceptualised knowledge and learning (knowledge accumulation) mainly from a rationalistic rather than a constructivist approach. Initially a lot of emphasis was given to R&D based innovation and measurable outputs such as patents. In a way, this high-tech fascination took a life of its own, limiting knowledge-intensive and innovative activities exclusively to high-tech industries such as pharmaceuticals and electronics. Currently there is increased attention for the importance of innovation in so-called low tech sectors (Tunzelmann and Acha
Another dimension that is intrinsically connected to the systems of innovation approach is change and renewal. It is therefore somewhat ironic that the approach has received a fair amount of criticism for delivering static, snap-shot analysis (Etzkowitz and Leydesdorff 2000; Carlsson, Jacobsson et al. 2002). This static approach seems to be endemic to the focus given to the structure of the innovation system, i.e. the actors, network relations and institutions. In contrast, Hekkert, Suurs, et al. (2007) and also Bergek et al. (2008) have pushed the research agenda more and more towards mapping the dynamics of innovation systems (see below). Related to this, it is important to specify what the actual outcome or teleological rationale for systems of innovation is. In other words, what is an innovation system for? On the one hand, innovation can be a means to an end. Initial work under the banner of national innovation systems, was predominantly geared to explaining uneven economic performance across countries (Lundvall, Johnson et al. 2002). As noted in the introduction, there is currently a wider set of developmental objectives at hand for which innovation is considered to be an important instrument. However, one can also argue that, in a strict sense, the main rationale for innovation systems is to generate innovation. This entails that innovation becomes an end in itself. It is important to keep this distinction in mind when measuring the performance of the system (see below).

A final dimension that obviously needs to be taken into account concerns methodology. It touches upon a sensitive issue where the surfacing of deeply rooted epistemological and ontological convictions concerning ‘the stuff that makes reality’ can evoke heated debate – as illustrated by the Science war debate between Flyvbjerg (2001) and Laitin (2003). Somewhat surprisingly, this debate has remained largely quiet within studies of innovation system. At best, methodological debate has been dealt with in an ad-hoc fashion mainly reacting to the flaws of neo-classical economics (Fagerberg 2005) and focusing on the specific techniques and instruments for research (Carlsson, Jacobsson et al. 2002). On the other hand, this lenient disposition has allowed for pluralistic and
eclectic approaches vis-à-vis the use of both qualitative and quantitative methods to conduct theoretically informed empirical analysis. This does however not imply that communication between proponents of qualitative and quantitative methods always comes easy. In this sense, a (brief but sound) methodological comparison of the different system innovation approaches is needed.

On the basis of the above outline we have gathered the following dimensions which allow for a systematic comparison of various systemic approaches to innovation:

1. System boundaries
2. Actors and networks
3. Institutions
4. Knowledge
5. Dynamics
6. Outcome / performance
7. Methodology

**A systematic comparison of systemic approaches to innovation**

The following coherent bodies of literature have been subjected to a comparative review: Sectoral Systems of Innovation (SSI), Technological Innovation Systems (TIS) and Socio-Technical Systems & Transitions (STS). We have restricted the search to a set of classic contributions that have laid out the principle ideas, notions and terminologies of the respective approaches.

*Definitions and System Boundaries*

The first approach, SSI, is defined in the following way: “A system of firms active in developing and making a sector’s products and in generating and utilising a sector’s technologies” (Breschi and Malerba 1997, p. 131). In this, a sector is a set of activities that are unified by some linked product groups for a given or emerging demand and which share some common knowledge (Malerba 2005). The most comprehensive and up-to-date definition is probably given by Malerba (2004, p. 16) in which a “sectoral system of innovation and production is composed of a set of new and established products for
specific uses, and a set of agents carrying out activities and market and non-market interactions for the creation, production and sale of those products”. This definition acknowledges the often intrinsic ties between production and innovation activities. However, Malerba (2004) acknowledges that the innovation system can be seen as an analytically separate system. In his writing and in the general understanding of this body of literature, the innovation system has also received most attention. In terms of boundary setting, the approach provides clear product-based guidelines. Sectoral systems of innovation can therefore include multiple technologies and transcend geographical boundaries. The emphasis on product-groups, e.g. automobiles, chemicals, construction, provides a useful connection to the NACE nomenclature which is the standard statistical classification of economic activities within the European Community. This facilitates the use of statistical data to analyse sectoral innovation patterns in a coherent way. However, the way SSI sets boundaries on the basis of products and demand may provide difficulties in the case of emerging demand and products (e.g. in the case of biotechnology or fuel cells). Due to this state of emergence, there is considerable technological and market uncertainty. How markets will develop and which users will adopt the technology is still an open-ended question. Ex-ante boundary setting of the system may therefore miss out on important factors and actors driving innovation.

The Technological Innovation System approach appears to be better equipped to deal with this state of emergence (Nygaard 2008). Pioneering work on TIS was carried out by Bo Carlsson and Rikard Stankiewicz (1991). They define it as “network(s) of agents interacting in a specific economic/industrial area under a particular institutional infrastructure or set of infrastructures and involved in the generation, diffusion, and utilisation of technology. Technological systems are defined in terms of knowledge or competence flows rather than flows of ordinary goods and services. They consist of dynamic knowledge and competence networks” (Carlsson and Stankiewicz 1991, p. 111). This definition acknowledges that a technological system can be national, regional and international, and, that a technology can cut across various industrial sectors. Biotechnology, for example, is employed by the pharmaceutical industry but also by food, agriculture and even mining. Given that technology is the common denominator in
TIS, this allows for a framework geared to studying how the configuration of actors, networks and institutions change over time as the technology develops (Carlsson 1997). Recently, the emphasis on dynamic analysis of TIS have received considerable impetus by explicitly focusing on the functions or processes taking place within the system of innovation (Hekkert, Suurs et al. 2007; Bergek, Jacobsson et al. 2008). It remains however a little ambiguous how exactly the boundaries of a technological domain are set.

Above approaches have been criticised by proponents of socio-technical systems for focusing exclusively on the production side and putting an analytical premium on firms (Geels 2004a). Instead, they argue, ST-systems encompass production, diffusion and use of technology in relation to so-called societal functions (e.g. transport, communication, nutrition). The elements of these systems, which in the above approaches are mainly constitutes of organisations, include for ST-systems also artefacts, knowledge, capital, labour, cultural meaning, etc. An important distinction within ST-systems is that between regimes and niches. “Technological niches and socio-technical regimes are similar kinds of structures, although different in size and stability” (Geels and Schot 2007, p. 7). This means that a regime and niche, in principle, are based on the same definition. Hoogma, Kemp et al. (2002, p. 19) define a regime as “the whole complex of scientific knowledge, engineering practices, production process technologies, product characteristics, skills and procedures, established user needs, institutions and infrastructures”. The ‘structuration’ of this complex is high, providing stable rules and coordinating effects on the actors that are implied by the regime. By default, ‘structuration’ in niches is looser, providing scope for heterogeneous rules and diffuse activities. This leads Geels (2004b) to argue that regimes generate incremental innovations as a result of stable and well-articulated rules whereas radical innovation belongs to the domain of unstable niches. Markard and Truffer (2008) remain however critical of the inconsistent way that empirical studies of ST-systems have delineated the system, either using it in a rather descriptive way as a synonym for sector or just in the form of a catchword. Transitions refer to changes from one ST-system to another (Geels et al., 2004).
Actors and networks

To determine how the various approaches conceptualise the role of different actors in the system we draw on the aforementioned distinction between primary and secondary actors. Both SSI and TIS can be regarded as firm-centred systems where the firm is the leading organisational unit responsible for innovation. “Firms are the key actors in the generation, adoption, and use of new technologies, are characterised by specific beliefs, expectations, goals, competences, and organisation, and are continuously engaged in processes of learning and knowledge accumulation” (Malerba 2004, p. 390). Conceptually, these approaches draw on the resource-based view of the firm where firms are seen as bundles of activity-specific competences (Penrose 1959). These competences can be technical, economic or organisational and constitute the resources that make one firm distinctive from others (Teece, Pisano et al. 1990). These competences are unevenly distributed giving rise to firm heterogeneity and to evolutionary processes of variety creation, replication and selection. This clearly demonstrates SSI’s and TIS’ conceptual pedigree to heterodox, evolutionary economic thinking and provides the micro-foundations that guide the aggregate behaviour of firms in the system of innovation. The actor set-up in these approaches is not exclusively limited to firms but also includes non-firm organisations such as universities, financial organisations, government agencies, local authorities and so on. However, it is fair to say that especially the SSI approach considers these types of organisations as secondary. This is not to say that they are less important for innovation, rather that they are more indirectly involved with innovation compared to firms. Especially in the case of emergent technologies universities unmistakably play a key role in terms of research and human capital formation. Micro-level conceptualisations of these actors have received far less attention in this literature.

The STS approach is critical of this neglect of other kinds of organisations beyond firms and calls for a broad range of actors to be considered in the system analysis. In lieu of bundles of resources, actors in the system are conceptualised as social groups based on strong coordination principles within the group (Geels 2004a). Instead of single organisations, STS takes the inter-organisational community or field as the unit of analysis under the banner of social groups. The disciplining devices to render a social
group its distinctive features are shared particular perception, problem-agendas, norms, preferences. In other words, this community is aligned through interrelated rules, i.e. regimes. These rules yield meta-coordination not only within a social group but also between social groups through interpenetration and, thus, provide scope for overlap. On the surface it may appear that SSI, TIS and STS adopt the same categorisations for the actors in the system (universities, public authorities, consumers, suppliers, banks, etc). It is however important to point out that they depart from quite different micro-foundations for organisational behaviour, originating respectively from a more economical (SSI/TIS) or sociological (STS) heritage.

This distinction also resonates in the ways that SSI/TIS and STS deal with the issue of networks and the conceptual pitfalls associated with it. Network analysis in STS jargon is primarily informed by Actor Network Theory (ANT). It maps relations that are simultaneously material (between things) and 'semiotic' (between concepts) and explores how such networks are formed, stabilised or destroyed. In STS, Actor Network Theory logic is used to align the different elements of a regime/niche. The distinction between regimes and niche parallels the distinction between so-called ‘hot’ and ‘cold’ situations (Callon, 1998). In a hot situation everything is contentious and thus results in an unstable ANT whereas in a cold situation the framings are peaceful and institutions (see also below) are stable (Markard and Truffer 2008). Focus is mainly on how relations and linkages emerge whereas ANT can be criticised for lacking explanation as to why networks emerge. The network concept is mainly used in a contextual rather than structural way. The latter is more the domain of SSI and TIS with a clear grounding in established network theories from economic sociology (Granovetter 1985; Powell and Grodal 2005). It emphasises that economic exchange is embedded in social relations and networks whether it be market relations or corporate hierarchies. This embeddedness can differ greatly across innovation systems. SSI and TIS has paid a lot of attention to the wide range of formal and informal modes of cooperation and interaction among actors. It has successfully demonstrated that networks exist because they integrate knowledge and competences that are widely distributed among firms and other organisations. Especially user-producer linkages and relations in value chains have received a lot of attention as
important sources of innovation (see e.g. Nygaard 2008 for the case of fuel cells and hydrogen technology). Nonetheless it needs to be noted that the recent turn towards functional analysis in TIS seems to have drawn attention away from network analysis.

**Institutions**

An important distinctive feature of the innovation systems literature is its emphasis on institutions (Lundvall and Maskell, 2000). Insights from institutional economics are used to explain that the organisation of firms and markets differs between sectors, technologies and territories. The distinction between the players of the game (organisations) and the rules of the game (institutions) has become commonplace in most studies of innovation systems. This caters for an important conceptual link.

“Agents’ cognition, actions, and interactions are shaped by institutions, which include norms, routines, common habits, established practices, rules, laws, standards, and so on. Institutions may range from ones that bind or impose enforcements on agents to ones that are created by the interaction among agents (such as contracts); from more binding to less binding; from formal to informal (such as patent laws or specific regulations vs. traditions and conventions). A lot of institutions are national (such as the patent system), while others are specific to sectors (such as sectoral labour markets or sector specific financial institutions)” (Malerba 2005, p. 385).

The way institutions are treated in the SSI, as well as TIS, approach is primarily as signposts for innovators. Institutions provide some sort of stability for firms guiding their behaviour in light of the intrinsic risk connected to innovation activities. Nooteboom (2000) conceptualises institutions as ‘enabling constraints’. They help and guide behaviour in one direction yet focus it away from alternatives. Therefore institutions are salient factors shaping innovation processes of firms and provide a forceful explanation for the uneven distribution of innovation across countries and regions (Asheim and Coenen 2005). However, the territorial varieties of the innovation system approach have been more consistent in treating institutions in a system perspective, drawing attention to institutional complementarities and multi-level institutional couplings (Hollingsworth
A systematic approach towards institutional frameworks seems to be somewhat of a weak spot in SSI and TIS analyses. Rather, focus goes to the impact of single institutions analysed in an ad-hoc way (Rohracher et al., 2008). Therefore the influence of institutions on sectoral and technological innovation systems can be regarded as contextual rather than structural. Those institutions that are often pointed out mainly belong to the regulative and cognitive domains: codes, standards and regulation for products and technologies. In comparison normative institutions receive far less attention.

The STS is, in contrast, highly ambitious when it comes to the variety of institutions and institutional frameworks that it takes into consideration. This is well illustrated by the definition of a regime where Hoogma, Kemp et al. (2002) have explicitly pushed the definition beyond the mainly cognitive original definition of a technological regime. Geels (2004a) has elaborated extensively on the regulative, normative and cognitive dimensions of institutions in connection to ST-systems.

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3 In fact, the turn towards functions seems to have replaced any analytical attention for the impact of institutions in technological innovation systems (Hekkert et al., 2007; Bergek et al., 2008).
Table 1 Examples of rules in different regimes

<table>
<thead>
<tr>
<th>Regime</th>
<th>Formal/regulative</th>
<th>Normative</th>
<th>Cognitive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technological and product regimes (research, development, production)</td>
<td>Technical standards, product specifications (e.g. emissions, weight), functional requirements (articulated by customers or marketing departments), accounting rules to establish profitability for R&amp;D projects (Christensen, 1997), expected capital return rate for investments, R&amp;D subsidies.</td>
<td>Companies own sense of itself (what company are we? what business are we in?), authority structures in technical communities or firms, testing procedures.</td>
<td>Search heuristics, routines, exemplars (Dosi, 1982; Nelson and Winter, 1982), guiding principles, (Elzen et al., 1990), expectations (Van Lente, 1993; Van Lente and Rip, 1999), technological guideposts (Sahal, 1985), technical problem agenda, presumptive anomalies (Constant, 1980), problem solving strategies, technical recipes, 'user representations'(Akrich, 1995), interpretative flexibility and technological frame (Bijker, 1995), classifications (Bowker and Star, 2000)</td>
</tr>
<tr>
<td>Science regimes</td>
<td>Formal research programmes (in research groups, governments), professional boundaries, rules for government subsidies.</td>
<td>Review procedures for publications, norms for citations, academic values and norms (Merton, 1973)</td>
<td>Paradigms (Khun, 1962), exemplars, criteria and methods of knowledge production.</td>
</tr>
<tr>
<td>Policy regimes</td>
<td>Administrative regulations and procedures which structure the legislative process, formal regulations of technology (e.g. safety standards, emissions norms), subsidy programs.</td>
<td>Policy goals, interaction patterns between industry and government (e.g. corporatism), institutional commitment to existing systems (Walker, 2000), role perceptions of government.</td>
<td>Ideas about the effectiveness of instruments, guiding principles (e.g. liberalisation), problem-agendas.</td>
</tr>
<tr>
<td>Socio-cultural regimes (societal groups, media)</td>
<td>Rules which structure the Spreads of information production of cultural symbols (e.g. media laws)</td>
<td>Cultural values in society or sectors, ways in which users interact with firms (Lundvall, 1988)</td>
<td>Symbolic meanings of technologies, ideas about impacts, cultural categories.</td>
</tr>
<tr>
<td>Users, markets and distribution networks</td>
<td>Construction of markets through laws and rules (Callon, 1998, 1999; Green, 1992; Spar, 2001); property rights, product quality laws, liability rules, market subsidies, tax credits to users, competitions rules, safety requirements.</td>
<td>Interlocking role relationships between users and firms, mutual perceptions and expectations (White, 1981, 1988; Swedberg, 1994)</td>
<td>User practices, user preferences, user competencies, interpretation of functionalities of technologies, beliefs about the efficiency of (free) markets, perception of what ‘the market’ wants (i.e. selection criteria, user preference)</td>
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Source: Geels (2004a) p. 906

In this framework, Geels draws extensively on institutional analysis. He suggests that the for short-term analyses, the institutional framework should serve as a relative constant having a strong structuring effect on the behaviour of actors, much in line with the way that institutions are treated in SSI and TIS. However, for longer-term analysis, i.e. in case of transitions from one socio-technical system to another, he argues that attention should be paid to social learning and institutional change. In light of the aforementioned distinction between regimes and niches he argues that existing institutional frameworks create path-dependence and lock-in into existing ST-systems (i.e. regimes). Niches, on the contrary, are “locations where it is possible to deviate from rules in the existing
regime. The emergence of new paths has been described as a process of mindful deviation (Garud and Karnoe 2001), where niches provide the locus for this process. This means that rules in technological niches are less articulated and clear-cut” (Geels 2004a, p. 912). In light of this conceptual comprehensiveness he acknowledges, however, that the complexity of this framework poses considerable challenges to making it operational for empirical research. Historical analyses obviously provide a useful way forward whereas analyses of contemporary institutional change may prove to be more cumbersome.

Knowledge
Knowledge is often seen as the crucial resource for innovation while learning is understood as an indispensable activity or process. All three approaches, SSI, TIS and STS, agree on this statement as a basic proposition. There are however striking differences between the innovation system approach and the STS approach respectively, in terms of conceptualising knowledge. Whereas the former highlight the importance of knowledge as a commodity susceptible to economic exchange, the latter pays more attention to knowledge in practice. Knowledge, thus, refers to ability to act rather than to a good (Ibert 2007).

For both SSI and TIS, knowledge is intrinsically tied to technologies. Sectors and technologies differ greatly in terms of knowledge domains and learning processes. The emphasis on technological knowledge does not mean that non-technological knowledge is ignored. Two generic types of knowledge domains receive particular attention. One knowledge domain is defined as “the specific scientific and technological fields at the base of innovative activities at the base of innovative activities in a sector” (Malerba 2004). The other domain concerns, albeit more vaguely defined, applications, users and demand for sectoral products. In similar vein, albeit in the context of national innovation systems, Jensen et al. (2007) contrast two forms of knowledge and modes of innovation. The Science, Technology and Innovation (STI) mode is based on the production and use of codified scientific and technical knowledge while the other is an experienced-based mode of learning based on Doing, Using and Interacting (DUI). The authors argue that
both modes need to be reconciled through formal processes of R&D that produce explicit and codified knowledge in combination with learning from informal interaction within and between organisations (e.g. through user-producer interaction) resulting in competence-building often with tacit elements. In empirical studies, technological knowledge and R&D have received most attention, partly because it can be measured in a relatively straightforward manner through R&D expenses and patents. Within the innovation system literature there is also a clear bias for economically useful knowledge. This is illustrated by the various dimensions that are used to analyse the relevance of knowledge for explaining innovative activities (Breschi and Malerba 1997). Knowledge may have different degrees of accessibility, understood as opportunities for gaining knowledge, cumulativeness, understood as the degree to which the generation of new knowledge builds upon current knowledge and appropriability, understood as the possibility of protecting knowledge from imitation and of reaping profits from innovative activities (e.g. through patents).

The STS approach acknowledges the importance of and need for the creation of technological knowledge for innovation much in line with the SSI and TIS approaches. In addition, it suggests a more elaborated understanding of the user side of technology that goes beyond passive knowledge diffusion. “Users also have to integrate new technologies in their practices, organisations and routines, something which involves learning, and adjustments. New technologies have to be ‘tamed’ to fit in concrete routines and application contexts (including existing artefacts). Such domestication involves symbolic work, practical work, in which users integrate the artefact in their user practices, and cognitive work, which includes learning about the artefact” (Geels 2004a, p. 902). Innovation can thus be understood as an outcome of the ongoing alignment of technology and the user environment in a co-evolutionary manner where adaptation takes place on either side. This caters for a more process-oriented understanding of the role of knowledge creation, exchange and use. It can therefore be argues that social learning has received more attention in the STS approach than in the SSI and TIS approaches. Partly this has to do with the stronger linkages to sociological theories, compared to the more pronounced economical orientation of SSI and TIS. According to Geels (2004a) social
learning refers to the reproduction or transformation of cognitive, normative and regulative rules through imitation or through the exchange of experiences. This manifested through adjustments of user representations, routines or shared expectation. The relative bias in favour of technological learning (SSI and TIS) or social learning (STS) clearly reverberates in the degree of novelty that is studied (see below).

Dynamics
The three approaches differ quite substantially in terms of analysing dynamics and change. The basic rationale for change in SSI is based on evolutionary processes –mainly oriented to incremental innovation. TIS have its focus on (particular) emergent technologies that have not yet achieved a break-through. STS is first and foremost geared to analysing change – especially from a broad societal perspective.

In the SIS framework, variety creation takes place at the level of products, technologies, firms, and institutions and is caused by the heterogeneity among actors. Systems can evolve as a consequence of the entrance of new agents into the system. Especially new actor entry (e.g. spin-off firms) is considered as particularly important for the dynamics, processes of change and transformation of a sector. Selection processes, in turn, reduce this heterogeneity and drive out inefficient or less progressive firms. Market plays an important role for selection even though the SSI literature also opens up for the possibilities of non-market selection (e.g. in the cases of the military and the health system). Changes in sectoral systems are thus the result of co-evolutionary processes of their various elements, involving knowledge, technology, actors, and institutions. These processes are often path-dependent and, through increasing returns and irreversibilities, susceptible for lock-in (Malerba 2004). A result of this evolutionary perspective is that the approach is mainly geared towards incremental change and step-wise improvement. Moreover recent contributions in the field of TIS have criticised the SSI approach for employing a snap-shot perspective that falls short of explaining the emergence of new sectors and technologies.
According to Hekkert, Suurs, et al. (2007) there is an exclusive focus on analysing the social and institutional structures of different innovation systems. “Since technological change is a dynamic process, which requires a transformation of the innovation system in which changes take place, a dynamic innovation system approach is needed to understand and better be able to guide its direction” (Hekkert, Suurs et al. 2007, p. 414). To remedy this shortcoming they suggest paying more attention to the various functions and activities that take place in an innovation system. In doing so, they seek to outline a more dynamism-friendly innovation system framework. Based on empirical studies they suggest the following set of functions to be applied when mapping key activities, and to describe and explain shifts in technology specific innovation systems. (1) Entrepreneurial activities, (2) knowledge development, (3) knowledge diffusion through networks, (4) guidance of search, (5) market formation, (6) resource mobilisation, (7) creation of legitimacy, counteract resistance to change. Hekkert, Suurs et al (2007) imported ‘dynamic’ notions from the technology systems approach (Carlsson and Stankiewicz 1991), and applied them to the interactions and momentum of innovation system’s functions. These authors proposed that, since functions influence each other, a virtuous cycle can be created among an innovation system. In this way, the systems behave non-linearly with several function interactions that create a momentum (called motors of change). This momentum will ultimately have a positive effect on the overall efficiency of the system at the time it stimulates structural change for systemic innovation. This inherently dynamic framework seems to be part of a wider tendency in the innovation system literature to focus not only on changes in the system, but also to changes of the system (Edquist 2005; Bergek, Jacobsson et al. 2008). It needs to be noted, though, that a weak spot of the functions approach to innovation systems is that attention for social and institutional structures seems to have been fully substituted, rather than complemented by the emphasis on functions. Derived of their social and institutional dimensions this turn runs the risk of treating innovation systems in an overly mechanical way.

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4 Bergek et al. (2008, p. 426) presents a comparative exercise of the nine known attempts to identify functions for assessing the dynamics of an innovation system.
The STS framework is primarily geared to analysing technological transitions whereas the innovation system approach has difficulties doing so by means of its focus on intra-system drivers, interactions and dynamics. Through its distinct use of the niche and regime concepts, the approach has proven to constitute a highly appropriate framework to understand and explain large-scale and discontinuous changes in socio-technological systems. In STS, technological transitions can take a long period of time – often more than one generation. During a transition, long periods of relative stability and optimisation are followed by relatively short periods of structural change. In this process a paradigm shift takes place and existing structures are broken down and new ones emerge (Rotmans, Kemp et al. 2000). The multi-level perspective is used in STS to explain such a dynamic process of change (transition), albeit “it is not seen as an ontological description of reality but as an analytical and heuristic framework” (Geels 2002, p. 1273). In particular, this perspective explains processes of variation and selection (niches), selection and retention (niches), and processes of reconfiguration and radical change (regime shifts). The macro level (landscape) consists in slow changing external factors. The meso level of socio-technical regimes refer to stability of existing technological developments. The micro level deals with the generation and development of radical innovations (Geels 2002). Various empirical studies bear evidence to this (Belz, 2004; Raven and Verbong, 2004; van Driel and Schot, 2004). These empirical studies are characterised by long time frames and historical analysis providing convincing accounts of substantial change processes. Markard and Truffer (2008) remain however critical of the near exclusive niche-based explanations for technological transitions. Secondly, as mentioned earlier, the bias towards sweeping historical accounts comes at the cost of individual actor behaviour and strategy making.

Outcome/Performance

In the SSI literature innovation is primarily seen as a means to achieve competitiveness. Through evolutionary processes of variation and selection are insufficiently innovative actors driven out of business as they are unable to support their competitive advantage and keep competition at bay. The European Commission defines competitiveness as the ability to produce goods and services which meet the test of international markets, whilst
at the same time maintaining high and sustainable levels of income, or more generally, the ability to generate, while being exposed to external competition, relatively high incomes and employment levels. In an increasingly globalising knowledge-economy, competitiveness is derived from differentiated capabilities (Malmberg and Maskell 1999). Such capabilities are created through innovation and varied and differentiated on a national and regional level. This leads Cantwell (2005) to argue that “innovation is a positive sum game that consists of the efforts of many to develop new fields of value creation, in which on average the complementarities or spillovers between innovators tend to outweigh negative feedback or substitution effects, even if there are generally at least some actors that lose ground or fail.” In contrast, the TIS approach is primarily concerned with technological change per se. Much attention goes to identifying the underlying factors which shape the virtuous cycles that, ultimately, cause the breakthrough of an incumbent technology. Carlsson, Jacobsson et al. (2002) noted that the measurement of the performance of TIS should be seen as the evaluation of the interconnection of the actors in the entire system. Individual performance may be measured as long as the focus of the total system is ultimately assessed. According to these authors, the level of analysis and the maturity of the system would ultimately determine the exact choice of performance measure (see methodological implications below).

The STS literature is first and foremost interested in how new configurations around socio-technical systems emerge and retain. Nonetheless, the underlying goals for transition management and strategic niche management are often connected to sustainability, understood as not just environmental benefits but also economic and social benefits. A lot of attention is paid to governance issues. Transition management seeks to orient societal dynamics to participatory defined sustainability goals for functional systems (energy, transport, agriculture) (Kemp and Loorbach 2005). Such a transition involves innovation in technologies and technical artefacts as well as changes in user practices, policies, markets, industrial structures and supporting infrastructures (Markard and Truffer 2008).
Methodologies

As noted earlier in this paper, innovation system studies have allowed the use of pluralistic and eclectic approaches vis-à-vis the use of both qualitative and quantitative methods to conduct theoretically informed empirical analysis. It is acknowledged that different ontologies, epistemologies and models of human nature imply the use of different methodologies in order to ‘gain’ knowledge from the social (and natural) world (Burrell and Morgan 1979). As noted throughout the previous sections, the adoption of any of the epistemological traditions in the social sciences (i.e. positivism, constructivism) do have methodological implications in the way an innovation system is approached (i.e. level of analysis), defined (i.e. system boundaries), and measured (i.e. system performance). For example, systems can be delineated at a different level of abstraction (i.e. definition of the level of analysis using a pragmatic approach). Complementarily, innovation systems may have certain characteristics that can be empirically identified (e.g. measuring system performance using a positivist approach), or the delineation of the boundaries of a system may change depending on the research question and the purpose of analysis (e.g. definition of system boundaries and identification of actors using a realistic approach) (e.g. Carlsson, Jacobsson et al. 2002; Markard and Truffer 2008). Somewhat surprisingly, this debate has remained largely quiet within studies of innovation systems. It is important to note that these methodological issues are intrinsically linked and affects one another – e.g. system boundaries, actors and networks, institutions, knowledge, dynamics and performance are affected depending on the level of analysis.

Below a summary of methodological implications for the different system innovation approaches are introduced, with special focus on system performance:

For defining the level of analysis, methods are mainly qualitative and choices are often pragmatic. Choices can be related to identify technologies, products, knowledge domains, firms or groups of innovations as unit of analysis. For the definition of system boundaries, (social) judgements are made by experts (i.e. researcher’s agreement on what constitutes a technology), relatively low-subjective measures are performed (i.e.
using technological distances to assess knowledge fields or patent analyses to unveil technological activity direction) or industrial classifications are used (i.e. for the identification of specific actors within a sector) (Carlsson, Jacobsson et al. 2002).

For measuring innovation performance in innovation system analyses, researchers and practitioners in the field face the challenge to generate fitting data, and to standardise the available methods. In such a case, one of the main challenges is to eliminate the trivial choices of innovation indicators (Kleinknecht, Van Montfort et al. 2002) –both quantitative and qualitative. However, it is not a matter of adding complexity to the way innovation performance is measured. The challenge is to identify different accurate methodologies and indicators in order to minimise possible bias induced by the researchers and their methods (Diaz Lopez 2008). An important tool for the standardisation of innovation system quantitative methods is given by the OECD’s Oslo Manual (OECD and EUROSTAT 2005), which is gaining popularity among academic and practitioners. Qualitative analyses face similar challenges. For qualitative based research, the interpretation and validation of arguments and use of relevant qualitative indicators are probably some of the most important aspects. Use of relevant primary and secondary data sources has also a major relevance.

A crucial aspect in innovation system quantitative studies has been to consider the nature of the innovation performance indicators. In general, innovation studies have used input, throughput and output innovation indicators. Innovation indicators have also been regarded of a qualitative or quantitative nature (Meyer-Krahmer 1984; Kleinknecht, Van Montfort et al. 2002; Flor and Oltra 2004). Another important conditioning factor is the availability of data sources and the quality of data collected (see summary in table 2). Ultimately, innovation performance indicators are used as proxies for innovation/technology/product generation, diffusion and use (Markard and Truffer 2008).
Table 2 Classification of performance indicators used in innovation system studies

<table>
<thead>
<tr>
<th>Type</th>
<th>Quantitative</th>
<th>Qualitative</th>
<th>Data Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input</td>
<td>Number of R&amp;D or/and engineering personnel</td>
<td>Market strategies</td>
<td>Innovation surveys</td>
</tr>
<tr>
<td></td>
<td>R&amp;D expenses</td>
<td>Formal R&amp;D department</td>
<td>Other type of surveys (labour, productivity, etc)</td>
</tr>
<tr>
<td></td>
<td>Ratio of R&amp;D activities/total R&amp;D (estimation of time)</td>
<td>Competitors pressure</td>
<td>Official statistics</td>
</tr>
<tr>
<td></td>
<td>Acquired technologies</td>
<td>Innovation barriers</td>
<td>Reports from industrial associations</td>
</tr>
<tr>
<td></td>
<td>Turnover</td>
<td>Strategic behaviour regarding innovations</td>
<td>Corporate reports</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Strategic use of resources, capabilities and competences for innovation</td>
<td>Case studies</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Technological diversity (e.g. number of technological fields)</td>
<td></td>
</tr>
<tr>
<td>Throughput</td>
<td>Patents solicited</td>
<td>Recycling share reuse share</td>
<td>Patent statistics</td>
</tr>
<tr>
<td></td>
<td>Revenues by technology management</td>
<td>(mainly for eco-innovation)</td>
<td>Corporate reports</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Timing/stage of development of technologies</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Regulatory acceptance</td>
<td></td>
</tr>
<tr>
<td>Output</td>
<td>Patents granted</td>
<td>Innovation goals</td>
<td>Innovation surveys</td>
</tr>
<tr>
<td></td>
<td>Innovation intensity</td>
<td>Innovation strategies (EI)</td>
<td>Patent statistics</td>
</tr>
<tr>
<td></td>
<td>LBIOS (literature-based innovation outputs)</td>
<td>Novel characteristics of new products with respect to comparable products</td>
<td>Reports from the industrial association</td>
</tr>
<tr>
<td></td>
<td>Number of innovations introduced</td>
<td>Innovative activities of clients and suppliers</td>
<td>Case studies</td>
</tr>
<tr>
<td></td>
<td>Turnover of the new products introduced</td>
<td>Mobility of professionals</td>
<td>Specialised magazines and industrial reports</td>
</tr>
<tr>
<td></td>
<td>Number of licences</td>
<td></td>
<td>Sustainability indices</td>
</tr>
</tbody>
</table>


Following on from the table above, SSI and TIS quantitative studies have mostly used financial indicators, R&D data, patents, bibliometric data (LBIOS), micro-data from innovation surveys, etc. SSI and TIS qualitative studies can be related to the use of indicators which refer to qualities or events in the system (and its unit of analysis). Examples of this we account: innovation barriers, stage of development of technologies and innovation goals. Mixed methods-based research has emerged as an alternative to validate quantitative (e.g. statistical methods using micro-innovation data) and qualitative (e.g. analysis of case study evidence) in SSI and TIS – since they offer triangulation techniques based on a pragmatist standpoint to underlie causal mechanisms of the innovation process. STS is mostly linked to qualitative methods based historical analysis, quasi-contemporary case studies and interactive action research. No (direct) quantitative or qualitative indicators can be identified as being used in STS research.

A common methodological pattern can be identified in most of TIS and SSI quantitative studies using micro-innovation data. First, they made assumptions in order to define what they consider as an ‘innovative firm’ (or what technology or knowledge domain is
considered as ‘innovative’). As a second step, indicators are created and the issue of reliability of the dependent variable(s) is assessed. Finally, a given set of explanatory and control variables are explored and empirically assessed (e.g. often by descriptive statistics). These are basic inputs for further empirical analysis (e.g. advanced statistics or econometric methods). Ultimately, the identification of factors driving innovation in firms and the measurement of innovative activities of them is obtained. Often, TIS and SSI quantitative studies use ‘formats’ of dependant variables mainly as binary variables (yes/no type), scaled (0, 1, 2, 3) and synthetic indices (either continuum or fixed). Proxy variables for innovation can only be relevant if they are supported by the use of sound data and methodology (Diaz Lopez 2008). No common methodological patters can be identified for the case of STS (qualitative) studies. The only case is perhaps when STS research describes historical events and some causal mechanisms based on the different stages of the multi-level perspective – i.e. emergence of the technology (niches formation), breakthrough of the technology, competition of the technology (regime transformation) and an explanation of the transformation dynamics (changes in the landscape). The lack of commonalities within this field could be explained by its less advanced level of methodological development (compared to SSI and TIS).
<table>
<thead>
<tr>
<th>System Boundaries</th>
<th>Actors</th>
<th>Networks</th>
<th>Institutions</th>
<th>Knowledge</th>
<th>Dynamics</th>
<th>Methodology</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sectoral Innovation Systems</strong></td>
<td>a. Based on an association of product groups (e.g., automotive), standardized through NACE b. Involves multiple technologies c. Not geographically bounded</td>
<td>a. Heterogeneous but mainly firm focused b. Links to wider industry innovation frameworks (e.g., technology roadmaps) c. Institutional and policy focus</td>
<td>a. Major focus on network analysis (qualitative and quantitative) b. Analysis is informed by social-economic network theories (organizational studies, Social Network Analysis)</td>
<td>a. Institutions are primarily conceptualized as institutions for innovation (marketing/innovation) b. Analysis is informed by social-economic network theories (organizational studies, Social Network Analysis)</td>
<td>a. Emphasis on knowledge as commodity (elaborate conceptualization) b. Emphasis on technological innovation and R&amp;D</td>
<td>a. Change is conceptualized as incremental co-evolution b. Frameworks as such are static (e.g., SO3)</td>
</tr>
<tr>
<td><strong>Technological Innovation Systems</strong></td>
<td>a. Based on a technological domain (e.g., biotechnology) b. May involve different scales of interaction c. Not geographically bounded</td>
<td>a. Heterogeneous but mainly firm focused b. Micro-foundation: heterodox economic theories (e.g., agency theory) c. Role of universities and state is more instrumental but not usually conceptualized</td>
<td>a. Some focus on network analysis, increased attention for network aspects in Functional Approach b. Analysis is informed by social-economic network theories (organizational studies, SNA)</td>
<td>a. Institutions are primarily conceptualized as institutions for innovation (marketing/innovation) b. Analysis is informed by social-economic network theories (organizational studies, Social Network Analysis)</td>
<td>a. Emphasis on knowledge as commodity (elaborate conceptualization) b. Emphasis on technological innovation and R&amp;D</td>
<td>a. Change is conceptualized as incremental co-evolution b. Especially the role of functions is conceptualized as such (emergent)</td>
</tr>
</tbody>
</table>
| **Socio-Technical Systems + Transitions** | a. Based on societal functions (e.g., mobility) b. Involves multiple industrial sectors & technologies c. Often geographically bounded (mainly nationally) | a. Heterogeneous involving broad spectrum of societal actors b. Conceptual theories of interaction networks for sector behaviour, preference for sociological conceptualizations c. Role of societal actors is considered as autonomous | a. Networks are implied as basic organizational structures between actors but little use of explicit network theory (emphasis is contextual rather than structural) b. Analysis is primarily informed by Actor Network Theory | a. Institutions are primarily conceptualized as institutions for innovation (marketing/innovation) b. Concepts of institutional dependencies and roles in terms of emphasis on niche activities | a. Emphasis on learning (emergent in practice) b. Focus on sociological and non-technological innovation | a. Change is conceptualized as incremental co-evolution b. Frameworks as such are dynamic (emergent) | Qualitative historical analysis and interactive, action research

Table 3. Summary of systemic comparison of SSI, TIS and STS
**Preliminary conclusions**

In this paper, we presented a systematic comparison the SSI, TIS and STS approaches (table 3 presents the summary of such a comparative devoir). This preparatory conceptual undertaking aimed to support the development of an integrated frame for analysis of systemic approaches to innovation. Such a framework could be used to provide insights on how to reconcile different demands and conditions vis-à-vis innovation from a sustainability and competitiveness rationale.

In the light of this background, the purpose of this concluding section is to provide preliminary insights on which dimensions the respective approaches differ or share commonalities, what their respective strengths and weaknesses are and some particular examples on how they may complement each other. It is not the purpose of this concluding section to rewrite the main commonalities and differences highlighted in the comparative analysis of the precedent sections nor to revise the findings of prior analyses (e.g. Markard and Truffer 2008). Alternatively, a brief list of evident commonalities of the different approaches can be enunciated as an illustration of their common strenghts.

The following points serve as an indicative ‘checklist’ of analytical aspects to be noted in future use of the proposed frame for analysis. This list includes the following considerations:

- All the approaches are implicated by ex-ante choices (e.g. researcher judgement delineates the boundaries of the system).
- At the general level, SSI, TIS and STS agree on encompass actors, networks and institutions, albeit they differ in basic foundations of them (e.g. different interpretation of knowledge in SST/TIS vs STS).
- They all have interactive notions (e.g. agents collaborating, knowledge diffusion, technologies evolving, networks interacting, etc)
- STS and TIS often involve changes and substitution in technologies and changes in circumscribing elements. Therefore, these approaches seem to be more dynamic than SSI.
- It may be adventured to say that they all occur at the regime level, dealing with incremental innovation which may accumulate and lead to radical/system
innovation. In SSI, a sector may be encompassed by groups of products in a regime (or a series of them). TIS may cut through different sectors and encompass several niches within a regime. Clearly, STS dynamics are mainly present at the regime level albeit radical technologies occur at the niche level.

The precedent sections noted clear differences are present in very basic foundations of these approaches (e.g. the way they see knowledge, the level they approach institutions, etc). A clear example of this was given by the contextual use of networks in SSI/TIS, whereas STS is greatly informed by Actor Network Theory. Regarding possible weaknesses, possible the most evident for TIS is related to their distraction from deeper institutions and network analyses. SSI faces a similar weakness for the analysis of institutions. A number of final remarks can be made related to methodological weaknesses of the aforementioned approaches. No (direct) quantitative or qualitative indicators could be identified as being used in STS research. Therefore, the complexity of this framework poses considerable challenges for making it operational in empirical research.

Regarding possible complementarities between the approaches, the STS and TIS approaches gives room for interesting analytical enrichments. STS uses a notion of technology where socio-technical configuration fulfils a function (e.g. societal). TIS are also based on the notion that innovation fulfils functions (e.g. systemic). For example, STS-technological regimes perform a function which guides technology trajectories and incremental change towards the same direction (Geels 2002, p. 1259). Similarly, technological trajectories can be influenced and guided by what TIS calls ‘entrepreneurs’ and public authorities – in particular for the functions of ‘guidance of the search’, ‘entrepreneurial activities’ and ‘market formation’. This is exemplified by Hekkert, et al (2007) in their motors of change (C and A) which may lead to virtuous cycles in the field of ‘sustainable’ technologies. Hekkert, et al (2007, figure 2, p. 426) explains that in this functions “societal problems can be identified and government intervention set limits to environmental damage. The establishment of goals may lead to new resources which lead to knowledge development and increasing expectations about technological options”
Complementarily, ‘entrepreneurs lobby for better economic conditions to make further technology development possible. They lobby for market formation since very often a level playing field is not present” (motor A). A recent article by Hekkert and Negro (2008) claims to provide empirical evidence based on ‘historical event analysis’ of five case studies which seek to support this claim. Clearly, more empirical research in the coming years will substantiate or disprove such a statement. Meanwhile, it would be interesting to explore the following idea: the seven dimensions in the socio-technical regime may have similarities to the functions of innovation systems (i.e. comparison of figure 5 of Geels 2002 and figure 2 of Hekkert, et al 2007 below).

A few thoughts can be introduced following the figure above, which may guide future comparative efforts for a more integrated approach of systemic approaches to innovation. At least, it may seem that the very basic dynamic notions of TIS and STS can inform and reinforce one another. The followings (explorative) aspects could serve as departing points:
• The 7 dimensions of STS seem to act in isolation. Geels explains them in a general and straightforward manner, where incremental process accumulate and eventually lead to radical innovations.

• The motors of change in TIS may help to explain interactions and feedbacks between the different dimensions in a STS. The mechanisms of technological transitions could be better explained if we order them in an analogy to the functions of an innovation system (since they both occur at the regime level), e.g. by explaining loops and feedbacks of motor of change (see figure below).

• The motors of change of a TIS may be in turn helped by the dynamics of strategic niche management (e.g. understanding fostering change of emerging technologies may help to the system functions).

To finalise this concluding section, it is important to note that answering the question whether innovation can act as a simultaneous driver for competitiveness and sustainability represents a tremendous ambition. Given the exploratory nature of this work, (current) additional research (both at the conceptual and empirical level) into drivers and bottlenecks of complex (multi level and multi actor) innovation processes will aim to solve this interrogation. The outcome of our review has made evident that better knowledge of the dynamics of innovation systems is needed in order to understand how to strengthen the impact of ambitious sustainability and competitiveness policy endeavours – such as the Dutch energy transition, which will be the object of a follow-up paper.
References


