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Understanding innovation processes

An overview of evolutionary innovation models

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FOREWORD

Responsible Ethical Learning with Robotics – REELER – is an interdisciplinary H2020 project funded by the European Commission with 1,998,265 EUR from the 1st of January, 2017 – 31st of December, 2019. Its main objective is to develop the REELER Roadmap for responsible and ethical learning in robotics. The project involves four European partners from the fields of anthropology, learning, robotics, philosophy, and economics, who work closely together in a research-driven collaboration between SSH-RRI and Robotic-ICT communities. Together, they aim to raise awareness of the human potential in robotics development, with special attention to distributed responsibility, ethical and societal issues, collaborative learning, as well as economic and societal impacts. The REELER Roadmap aims at aligning roboticists' visions of a future with robots with empirically-based knowledge of human needs and societal concerns, through a new proximity-based human-machine ethics that takes into account how individuals and communities connect with robot technologies. REELER's comprehensive research methodology includes a design-anthropological approach to onsite studies of roboticists' laboratories and daily work, as well as onsite ethnographic studies and impact studies of present and potential affected stakeholders. The project also includes quantitative research in geographical distribution of patents and an AMB (agent-based model) research approach. Furthermore, the project makes use of novel methodologies to give both robot-designers and affected stakeholders a space for mutual exchange about a robotic future, built around a number of REELER's ethnographic case studies of robots being developed in Europe. These novel methods include experiments with mini-publics, role play, social drama, and also explorations of the established sociodrama approach with professional sociodramatists. REELER aims to include all relevant aspects of this research in the roadmap, which will present ethical guidelines for Human Proximity Levels (HPL) in design work, as well as prescriptions for policy makers and robot-designers for how to include the voices of new types of users and affected stakeholders. The project aims to present an agent-based simulation of the REELER research to be used by roboticists and policymakers. The working papers presented in this series present ongoing research results, literature reviews, and position papers.

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UNDERSTANDING INNOVATION PROCESSES: AN OVERVIEW OF EVOLUTIONARY INNOVATION MODELS

By Sophie Urmetzer and Andreas Pyka

ABSTRACT

Since the 1970s, the view on innovation of political and corporate decision makers has gradually changed from a linear perspective (demand-pull and technology-push) to more complex models considering a diversity of influencing actors as well as the importance of feedback effects during the process from the idea creation to the release of the novelty on markets (Kline and Rosenberg 1986, Etzkowitz and Leydesdorff 1999). The theoretical founders of these more complex and more realistic approaches to the analysis of the phenomenon of innovation were among others, Rosenberg (1976), Nelson and Winter (1982), Rothwell and Zegveld (1981) or McKelvey (1994). On the basis of their theoretical underpinnings different lines of models have evolved to understand the process of the production of new knowledge and to foster innovation. This survey paper presents an introduction to the conceptual framework of innovation systems (Freeman 1989, Lundvall 1992, Nelson 1993) and the triple helix model (Etzkowitz and Leydesdorff 1999) as approaches to under-stand innovation processes within their specific socio-economic and political contexts from two different systemic perspectives. To comprehend the mechanisms shaping industrial innovation processes on a more operational level, evolutionary economists have described the phenomenon of innovation networks, which will be introduced subsequently. Before we do so, we will take a closer look at the sources and diffusion mechanisms of the most crucial resource of innovation, namely knowledge. By introducing the new paradigm of knowledge production, the mode 2 (Gibbons et al. 1994; Cohendet and Joly 2001) we take account of the particular knowledge flows between agents of the innovation process. This will lay the foundation for a better understanding of the processes steering the innovation systems, the triple helix and innovation networks. We will argue that these notions are of fundamental importance for informing innovation policy confronted with the innate uncertainty within complex socio-economic environments determined by: (1) a high degree of transdisciplinarity, (2) a variety of stakeholders, (3) alternative communication channels, (4) environmental and societal challenges of global dimension as well as (5) novel technologies like artificial intelligence blurring the boundaries between agency and medium.

1.0 Opening

It is widely recognized that ‘‘the most fundamental resource in the modern economy is knowledge and, accordingly, the most important process is learning’’ (Lundvall 1992; 1). Knowledge has always played a crucial role in economies and the skills to create artefacts have been passed on and improved from generation to generation, building up competences and skills that facilitated economic growth. With the onset of industrialization, however, life conditions changed rapidly and living environments were not as stable as they used to be. Consequently, the ability to adapt to new conditions, i.e. the ability to learn became much more fundamental (Lundvall 1994). Since the early 1980s, when traditional industries struggled with excess capacity and falling productivity, governments ran into deficits and income declined, the new post-industrial vision of a knowledge-based economy came to life. It became obvious that economic wealth was more and more decoupled from material growth and rather tended to be secured through the creation, production, distribution and consumption of knowledge and knowledge-based products (Harris 2001).

2.0 A new mode of knowledge production – mode 2

Considering this fundamental role of knowledge in contemporary economies raises the question of where this knowledge is produced and stored and who controls and distributes it. While this power has for quite some time been the privilege of public scientific institutions, a new mode of knowledge production is now undermining this monopoly: the mode 2 (Gibbons et al. 1994; Cohendet and Joly 2001). This new way of knowledge production is said to be "socially distributed, application-oriented, trans-disciplinary, and subject to multiple accountabilities" (Nowotny et al. 2003; 179). Whereas mode 1 implied pure science being generated in an exclusive environment and sometimes afterwards applied, transferred or managed otherwise, a mode 2 knowledge generation is motivated by topics and research designs that are embedded in the social system. Research agendas are not exclusively fixed in a top-down manner, but become more and more a product of social discourse. This requires a dialogue between research subjects and objects and at the same time blurs traditional boundaries between disciplines and between basic and applied research (Gibbons et al. 1994, Nowotny et al. 2003). In short: research is becoming more directly relevant for society.

2.1 Knowledge for society

To create solutions to problems instead of creating publications seems to be a purely positive characteristic of mode 2 knowledge production. Especially with view on the currently pressing global challenges like climate change, resource depletion, distributional questions or the demographic development it seems imperative to put most effort in research addressing a transformative system change based on what has been termed transformative science (Grunwald 2015, Schneidewind et al. 2016). This approach, which targets radical transformation of existing institutions and routines, would surely not have reached such high priority on a research agenda designed by an exclusive research community steered by current politicians in line with the powerful incumbent industries - simply because the currently powerful do not have an interest in changing anything. Furthermore, findings of technological impact assessment and more recently of responsible research and innovation studies show that discursive deliberation involving different societal stakeholders increases critical reflection of advantages and disadvantages, potential and risks of new technologies (Schneidewind et al. 2016). Another gain from the new mode of knowledge production obviously is the tendency of increasing collaboration of formerly distant disciplines (Nowotny et al. 2003). Using inter- and transdisciplinary approaches to explore theoretical or practical issues has been found to fundamentally improve creativity and lead to more creative solutions (see, e.g., Paci and Usai 1999, Kanter 2000, Blackwell et al. 2009). At the same time, mode 2 comes along with an intensification of research collaboration between universities, industry, government organizations and hospitals (Godin and Gingras 2000). Together with the emergence of other knowledge production communities - such as think-tanks, activist groups or management consultants that engage in research - (Nowotny et al. 2003) these new configurations contribute to the development of alternative ways to produce knowledge. In line with the evolutionary approach to economic development, such variety of information flows create highly innovative environments, for "innovation often demands the gathering and storing of types of information different from those obtained by scientists" (Kline and Rosenberg 1986; 281).

2.2 Quality issues

The new paradigm of mode 2 knowledge production has been widely welcomed due to the de-scribed advantages. However, it has been adopted with mixed feelings in other circles. Some universities and traditional scholars oppose to the celebration of the "democratization" of knowledge production for reasons connected to the quality, the freedom and the openness of basic research. While, firstly, the quality of advanced scientific research (mode 1) is traditionally secured by the peer-review process of scientific publications, results from mode 2 knowledge production often need to fulfil other criteria quite different from the objective of scientific excellence. Quality of mode 2 knowledge will rather have to be evaluated on the basis of its relevance for the users or its adequacy to solve a specific problem (Fujigaki and Leydesdorff 2000). The second argument against the establishment of the new way of knowledge production is the fear of a commercialization of scientific research (Nowotny et al. 2006). Where public expenditure for academic research is ac-companied or taken over by private investment, commercial interests are expected to be served increasingly which threatens scientific autonomy and freedom. The third reason why mode 2 is regarded with skepticism by some is connected to the latter. The reduction of the entire knowledge production to the creation of solutions, termed solutionism, may run risk of destroying the traditionally basic force of scientific progress and its warranty to openness: the desire to under-stand the world (Strohschneider in Grunwald 2015).

2.3 Reconciliation of the modes

The locus of production of the fundamental resource in modern knowledge-based societies is a highly debated issue. Before the diversification of knowledge production was coined as mode 2 in the 1990s (Gibbons et al. 1994) several authors have described similar phenomena with notions such as finalized science (Böhme et al. 1973, see also Schäfer 2012) or post-normal science (Funtowicz and Ravetz 1993, Elzinga 1996). Although mode 1 is by no means the "normal" or "intuitive" procedure of knowledge production the observation of a trend of departure from it has created anxiety among established science communities (i.e. typical mode 1 institutions) (Weingart 1997). But in the context of the increasing knowledge base in our modern societies and especially with view on the globalized challenges humanity is facing, the competition between the different modes is probably obsolete. Instead of fostering resentment against transformative approaches to socially relevant scientific questions, academic science should seek to take advantage of socially distributed knowledge production and vice versa. The central market place, the Greek agora - a place for the public and for politicians, a market as well as a place of social discourse –, enriched by the conveniences of new communication technologies and cutting-edge research methods, can serve as a model for the production and application of relevant knowledge (see, e.g., Gibbons et al. 1994).

3.0 Innovation systems

Following the previous section, it is assumed that the creation and diffusion of new knowledge is a social and interactive process (mode 2). Since new knowledge can potentially be acquired anywhere in the social system, it is an impossible task to backtrack the locus of a single innovation, let alone to understand the processes and drivers of novelty creation, its further development and diffusion in an industry, an economy or a society. Does this fact make attempts to understand and systematically facilitate innovation obsolete? Of course not. Taking on a new perspective, innovation economists, sociologists, but also policy makers within the European Union and other OECD countries have bowed out of the idea that a pure strengthening of new scientific discoveries will directly trigger practical innovation via applied R&D by the private sector (Schot and Steinmueller 2016). Instead, innovation and innovative capacity of a political or economic entity has to be regarded from a holistic perspective. One way to describe, comprehend, explain - and possibly shape - the dynamics and the success factors of an entity's (e.g. a nation, region or a sector) innovative capacity is the innovation systems approach. The conceptual framework has been coined by Freeman (1989), Lundvall (1992) and Nelson (1993). It has since then been subject to both critique and further refinement, but generally is used today to inform scientists to understand innovation, policy makers to design innovation policies and firms to formulate innovation strategies (Edquist 1997, Lundvall 2007).

3.1 Knowledge-based

The notion of innovation systems is a framework to examine the collective of the actors and institutions involved in innovation and their interactions within defined boundaries. Here, the term inter-action can mean a multitude of relations. The most relevant ones for innovation processes are knowledge-based activities like learning, searching and exploring (Lundvall 1992, Edquist 1997). The aim of the innovation systems approach is to disclose how differences in the configuration and the interactive learning and informing of the included actors and institutions are responsible for certain economic outcomes. For an understanding of the learning processes on the micro-level of the individual firm, it is important to consider certain characteristics of knowledge and the consequences for its acquisition (=learning). Two general assumptions from an evolutionary perspective on knowledge are central: (1) knowledge is more than information and (2) knowledge can be individual and tacit (Polanyi 1958). Instead of regarding economic agents (firms or individuals) as containers to be filled with knowledge, the systems' approach tries to reveal just how the knowledge can be taken up by the agent. Consequently, a successful innovation system offers organizations, relation-ships and career patterns that promote the acquisition of knowledge and the building of relevant competences. Since the innovation system itself is also subject to change while adapting to changing environments and circumstances, the specific patterns of collaboration and communication are also dynamic (Lundvall 2007).

3.2 Path-dependent

This leads us to another basic assumption behind the concept of innovation systems: those institutions that directly promote the acquisition and diffusion of new knowledge are embedded in a specific socio-economic system (Lundvall 1992). Within this system, "political and cultural influences as well as economic policies help to determine the scale, direction and relative success of all innovative activities" (Freeman 2002; 194). This explains why there is usually more than one model that delivers economic success (Hall and Gingerich 2009) – even at the same point in time and state of development. Consequently, the set-up of a specific innovation system is hardly a matter of intention and design. History and geography matter and on top of that: coincidence. Small events may provoke unforeseeable feedback effects determining the direction of innovation and development and thus shaping the system in a particular way. At the same time, the historical and path-dependent development of innovation systems makes them relatively inert and resistant to (deliberate) quick change and thus prone to technological lock-in (Edquist 1997, Hekkert et al. 2007).

3.3 Non-optimal and dynamic

Considering the evolutionary and unintended nature of innovation systems, it becomes clear that they will never reach an optimal state (Edquist 1997) but offer an experimental environment which includes failure. While the actors are expected to be in constant search for technological and institutional solutions, innovation systems are subject to change on all levels of consideration. Not only do firms change with the emergence of novelties created by themselves or within their sectors, also institutions adapt to new conditions and change or are replaced. This way, new regulation, entry and drop-out of firms and organizations, and other events change the character of an innovation system over time in persistent pursuit for better responses to current problems. In this note, Hekkert and his colleagues (2007) add a time perspective to the innovation system framework. They suggest mapping the dynamics of a system rather than the structure at one point in time since the success of an innovation system does not only depend on the structure of the involved actors and institutions (as initially suggested by the founders of the framework), but on the activities inducing change.

3.4 Measurable

In order to map determinants of innovation, evaluate and compare the performance of innovation systems and identify clear policy targets, it is fundamental to relate the configuration of their components (i.e. actors, networks and institutions) to their performance (Patel and Pavitt 1994, Jabobsson and Bergek 2004, Hekkert et al. 2007). As an instrument to achieve this connection, Hekkert and colleagues (2007) have identified seven functions to be tested to measure an innovation system's performance (based on own empirical studies and previous works by Liu and White 2001, Johnson 2001, and Jacobsson et al. 2004): (1) entrepreneurial activities; (2) knowledge development; (3) knowledge diffusion through networks; (4) guidance of the search; (5) market formation; (6) resources mobilization; and (7) creation of legitimacy. These functions are not independent from each other, but rather positively or negatively affect each other in a non-linear way, thus either accelerating or slowing down processes of change (Hekkert et al. 2007).

3.5 Multi-level

Regarding the level of analysis, the innovation systems framework is quite flexible and has been adapted to different purposes during the last two decades. On the national level, innovation systems have been explored for instance by Freeman (1989) who analyzed the national innovation system of Japan or by Edquist and Lundvall (1993) who compared the Danish and the Swedish national innovation systems. The regional innovation systems approach takes smaller geographical units into focus arguing that in many cases the sub-national region is the venue of networking, learning, and intervention and support by the government (Cooke 1992). Franco Malerba was the one who transmitted the framework to single sectors (2002). The sectoral system of innovation has been employed for the analysis of various sectors, such as the pharmaceutical, the chemical or the software sector in Europe (see various authors in: Malerba 2004). The analyses prove that sectors do vary a lot in their set of relevant actors, relations and institutions. While successful innovation in pharmaceutics and biotechnology requires a strong science base and strict intellectual property protection, the software sector will perform best when producers closely connect to users and integrate their experience of application into novelty development (Malerba 2004). The technological systems described by Carlsson and Stankiewicz (1991) and further elaborated by Jacobsson and Johnson (2001) are also made up of actors, their networks and institutions – innovation system components in this case interacting in a specific technology area. Walker (2000) pointed to the inherent inertia of large technological systems embedded in a comfortable network of actors and institutions that tend to prolong the use of a certain technology even when a new and superior one is ready to replace it. Such technological lock-in (or as Walker termed it: systemic entrapment) can be best understood and ideally better overcome by detecting the specific power relations and infrastructures associated with this incumbent technology. On the other hand, the recognition of a favorable configuration of a technological system may inform policy makers ex-ante to support innovative capacity for a chosen technology (Metcalfe 1995).

4.0 The triple helix

While innovation systems research considers the firms as chief drivers of innovation (Lundvall 1992, Nelson 1993) and other approaches focus on the role of the state (e.g., Sábato 1975), a more recent thesis also acknowledges the critical role of universities in processes of change: The triple helix model depicts all three relevant spheres – industry, academia and government – as three interwoven strands of institutional entities. The model was developed in the late 1990ies by Etzkowitz and Leydesdorff (1999, 2000) to better understand the co-evolutionary processes that have been observed between the institutional arrangements of an economy and the evolutionary functions of the system (Leydesdorff and Meyer 2006). While each of these spheres follows its particular agenda of wealth generation (industry), novelty production (academia) and public control (government), respectively, they influence and co-evolve with each other. An overlay network of dynamic bilateral and trilateral communication, cooperation and dependence between and within the three keeps the helix in motion by constantly changing (power) relations.

4.1 Institutional reorganization

The analytical model has been developed as a tool to describe the inherent dynamics of the innovating systems that have so far only been described in their relatively static institutional set-up (Etzkowitz and Leydesdorff 2000). This way, the triple helix approach explores the interdependence among the institutional elements of innovation systems and the observed new ways of knowledge production (mode 2) to understand how communication and collaboration shape the current reorganization of institutional infrastructure. As the metaphor suggests, the helices (industry, universities and government) are interdependent strands of organizational units that are constantly changing within themselves and inducing change in their relation among each other. The components and their relations are never completed but rather find themselves in a constant process of transition shaped by the flux of the modern resource of knowledge (ibd.). These processes are blurring the boundaries of the spheres: While universities or policy makers increasingly under-take entrepreneurial ventures, industry engages in education of their employees (Etzkowitz 2008).

To sum it up, the triple helix model takes account of three current developments: the more central role of the university in innovation, stronger collaboration of the three institutional spheres and a reciprocal role shift between the same, which means that each institution takes over parts of the formerly strictly separated tasks of the other two (Dzisah and Etzkowitz 2008).

5.0 Innovation networks

The theories introduced above increase our understanding of the systemic infrastructure underlying innovation processes. Their recognition is inherently fundamental for deliberate systemic intervention and thus crucial for any form of governance or exertion of influence on economic development and structural change. For a more operational approach to the phenomenon of innovation, however, it is more relevant to transmit the renunciation of the linear view and the prevailing knowledge orientation on innovation processes to an actor-based level. Keeping in mind our initial assumption that knowledge has become the central resource of present day's economies (Lundvall 1992) the question remains how this resource is actually distributed among the participants of an economy.

5.1 Knowledge flow through networks

Industries have been observed to consist of individual actors that are organized within firms of different sizes and networks of knowledge-exchange and co-operation between them and other relevant stakeholders (Pyka 2002). Such networks comprise – apart from commercial participants –

also research institutions, educational organizations or (other) public bodies. The set-up of innovation networks varies in its degree of formality. Freeman (1991) classified them along a gradient from tightly arranged cooperative contracts (e.g. joint ventures or joint R&D agreements) on one end to the informal exchange of knowledge and competencies between firms or their employees on the other and involves also financial engagement (e.g. direct investment or government sponsored research programs) and the sharing of relevant knowledge and information somewhere between the two. Interestingly, several studies have shown that for inter-firm knowledge exchange informal networks are more important than formalized collaboration contracts. Furthermore, such informal ties are usually the prerequisite for more formal arrangements later and tend to be more stable (see, e.g., von Hippel 1989, Jagger and Miles 1989, Hakanson and Johanson 1988, Pyka 1997, Malerba and Torrisi 1992).

5.2 Motives for networking

Mainstream economic approaches have had difficulties to explain the phenomenon of innovation networks and tended to regard them as unstable and inefficient because they increase transaction costs (Pyka 2002). If knowledge obviously is such a valuable resource for the innovative performance of firms, why do they voluntarily share it with their competitors? Pyka (2002) identifies three different strands of explanatory theories for the emergence of innovation networks and argues to abandon the two incentive-based explanations (i.e. inter-firm cooperation as favorable choice for a firm in specific cases applying (1) the production function or (2) transaction cost calculations). Instead, the knowledge-based theories seem to hold more explanatory power. By putting knowledge at the center of economic analysis, networks must be seen as an essential determinant in the creation of novelty within an industry. In bringing together different technological and economic know-how, new technological opportunities arise from technological complementarities and synergies (ibd.; 153). However, the fact that cooperation triggers and accelerates innovation on the level of an industry or an economy, still does not explain the willingness of individual enterprises to share their specific knowledge resources. On the firm level, Hagedoorn and Schakenraad (1989) have identified different motives to engage in innovation networks. On the basis of their empirical analysis of information technologies, biotechnology and new materials they conclude that generally “the search for new markets and entry, the reduction of the period innovation, the technology complementarity of partners and monitoring technological opportunities” (Hagedoorn and Schakenraad 1990; 13) were the major motives that let firms collaborate with their competitors. The sharing of costs and risks - often associated with inter-firm collaboration - obviously played a negligible role.

5.3 Incumbents and start-ups

Since the 1970s, a wide range of industrial production is based on knowledge including R&D, but also other intangibles (e.g. design, engineering, training, marketing and management) (Powell et al. 1996, Mytelka 2001). Such industries are often characterized by a number of strong ties between incumbent firms and start-ups – economic agents of total disparity concerning their access to re-sources, their economic expectations and their flexibility to react to changing markets. Collaboration between such contrary partners in knowledge-intensive fields like the biotechnology industry has been found to benefit both sides: established firms get access to cutting-edge knowledge and high creativity from the start-ups that are often university spin-offs, and the entrepreneurs profit from the infrastructure and other resources (also sometimes financial) offered by the incumbents (Pyka and Saviotti, 2005). This way, the established large market leaders can avoid losing touch with rapid technological developments as well as novel consumer demand based on changed values and expectations. By collaborating with competing newcomers in their industry, incumbents are better prepared to adapt their competences and technological outfit in order to escape the creative destruction always associated with technological change (Schumpeter 1942). More user-oriented industries like the information and communication technologies have shown to increase their innovative capacity with the help of direct contact to their consumers in user-producer networks. These links guarantee a more careful consideration of consumer needs and expectations already during the development process (Lundvall and Johnson 1994, Keil and Carmel 1995, Ainamo and Pantzar 2015).

5.4 Network architecture

Since the importance of informal and formal networks among economic agents for the innovative performance of industries has been acknowledged, scholars have been occupied with exploring the evolving structure of a network as well as varying positions of network participants with the toolkit of social network analysis (see, e.g., van der Valk and Gijsbers 2010). Depending on the purpose of the network and the types of actors and flows between them, certain network configurations have proven to be more efficient than others in promoting overall innovative activity and certain actor positions have been found to play distinguished roles within the network (Granovetter 1973, Burt 1992, Provan et al. 2007). Several studies on empirical and virtual bases, for instance, revealed that a so-called small-world network structure (a network consisting of several strongly connected clusters that are connected to each other with only few ties; Milgram 1967, Watts and Strogatz 1998) improved the participating firms' ability to master the trade-off between the exploitation of current technology and the exploration of new technologies (Lazer and Friedman 2007, Fang et al. 2010). An also quite characteristic pattern of innovation network evolution has been found to be the scale-free network (a network including single very well connected actors and a majority of very scarcely connected ones; Barabási and Albert 1999), which tends to emerge in constantly growing configurations where new entrants preferably connect to already well connected actors. From the perspective of a single firm, it is of strategic importance whether it finds itself among the periphery actors or in a hub position to which new entrants are most willing to connect (see e.g., Jarillo 1988 or Gulati et al. 2000).

6.0 Overview

The paper provides an overview of current innovation theories that are based on evolutionary thinking. The following table (Table 1.1, next page) displays the type of framework, the type of theory, a definition, the founders as well as the theoretical origin of the four concepts introduced above.

	Mode 2	Innovation Systems	Triple Helix	Innovation Networks
Type	New paradigm of knowledge production	Conceptual framework (Edquist 1997); grounded theory (Lundvall 2007)	Analytical model	Graph-theoretical mathematical model; social network analysis
Definition	"A new paradigm of knowledge production (…) which [is] socially distributed, application-oriented, trans-disciplinary, and subject to multiple accountabilities." (Nowotny et al. 2003; 179)	In a narrow sense: "The network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies." (Freeman 1987; 1) In a broad sense: "All parts and aspects of the economic structure and the institutional set-up affecting learning as well as searching and exploring – the production system, the marketing system and the system of finance present themselves as subsystems in which learning takes place." (Lundvall 1992; 12)	"A recursive overlay of interactions and negotiations among the three institutional spheres [i.e. industry, academia and government; the authors]. The different partners engage in collaborations and competition as they calibrate their strategic direction and niche positions." (Etzkowitz and Leydesdorff 1999; 113) Three sub-dynamics: the diffusion of technologies through markets, the history of technologies that propels the processes of change and restructuration, and the reflexive levels of control, including government and private enterprise (Etzkowitz and Leydesdorff 1999; 112)	Innovation networks consist of actors and links between the actors which serves as channels for knowledge flows. Innovation networks can be either formal, i.e. contract based or informal and may include besides firms also universities and other research organisations as well as consumers. Industrial innovation processes, in particular in knowledge-based industries are frequently organized in innovation networks, which dynamically evolve over time.
Founders (year)	Gibbons et al. (1994)	Freeman (1987); Lundvall (1992)	Etzkowitz and Leydesdorff (1999)	Freeman (1991)
Theoretical origin/ predecessors	Finalised science (Böhme et al. 1973), post-normal science (Funtowicz and Ravetz 1993; Elzinga 1996)	Interactive learning theories, evolutionary theories (Edquist 1997)	Sociological theories of institutional retention, recombinatorial innovation and reflexive controls (Etzkowitz and Leydesdorff 2000)	Social networks (Granovetter, 1973)

Table 1.1: Overview of the different evolutionary innovation models.

7.0 Final remarks

Common to all of the above introduced approaches is their rejection of the idea of a linear innovation process. Innovation systems, mode 2, triple helix and innovation networks all highlight the high degree of complexity characteristic for knowledge generation and diffusion processes in which heterogeneous actors ranging from established firms to knowledge-based start-ups, from innovation policy makers to creative users and from public basic research institutions to industry research institutes are involved. In an open development characterized by true uncertainty any kind of optimization approach has to fail in guiding the learning processes of the involved agents (Pyka 2014). Instead an experimentally based acceptance of failure and adaptation is required which dynamically explore new links in a multidimensional knowledge space with unforeseen developments and surprises. The system-oriented approaches focus on the mutual dependence of different actors' populations in innovation processes which generate complex co-evolutionary dynamics. The innovation network approach gives hints on how knowledge is generated and transferred on the actors' levels and how the channels of knowledge transfer affect their innovation performance. In this sense, both the systemic and the individualistic approaches are highly complementary and useful in informing decision makers about characteristic patterns of knowledge creation, which fuels the *capitalistic engine of progress* (Nelson 1990).

REFERENCES

Ainamo A., & Pantzar M. (2000): Design for the information society: What can we learn from the Nokia experience? The Design Journal, 3(2), pp. 15-26.

Barabási A. L., & Albert R. (1999): Emergence of scaling in random networks. Science, 286(5439), pp. 509-512.

Blackwell A. F., Wilson L., Boulton C., & Knell, J. (2009): Radical innovation: crossing knowledge boundaries with interdisciplinary teams (No. UCAM-CL-TR-760). University of Cambridge, Comput-er Laboratory.

Böhme G., Daele W. V. D., & Krohn W. (1973): Die Finalisierung der Wissenschaft/The Finalization of Science. Zeitschrift für Soziologie, 2(2), pp. 128-144.

Burt R. S. 1992: Structural holes: The social structure of competition. Cambridge, MA: Harvard Uni-versity Press.

Carlsson B. and Stankiewicz R. (1991): On the nature, function, and composition of technological systems. Journal of Evolutionary Economics 1, pp. 93–118.

Cohendet P. and Joly P.-B. (2001): The Production of Technological Knowledge: New Issues in a Learning Economy. In: Archibugi D. and Lundvall B. Å. (eds.) (2001): The globalizing learning economy. New-York: Oxford University Press, pp. 63-82.

Cooke P. (1992): Regional Innovation Systems: Competitive Regulation in the New Europe. Geoforum 23, pp. 365–382.

Dzisah J., & Etzkowitz H. (2008): Triple helix circulation: the heart of innovation and development. International Journal of Technology Management & Sustainable Development, 7(2), 101-115.

Edquist C. (1997): Systems of innovation: technologies, institutions, and organizations. Psychology Press.

Edquist C. and Lundvall B.-A. (1993): Comparing the Danish and Swedish Systems of Innovation. In Nelson R. (ed.) (1993): National Innovation Systems. A Comparative Analysis. Oxford: Oxford University Press.

Elzinga A. (1996): Shaping worldwide consensus—the orchestration of global climate change re-search. Internalism and Science. Cambridge: Taylor Graham Publishing, pp. 223-253.

Etzkowitz H. (2008): The triple helix: university-industry-government innovation in action. Routledge.

Etzkowitz H. and Leydesdorff L. (1999): The Future Location of Research and Technology Transfer. Journal of Technology Transfer 24, pp. 111-123.

Etzkowitz H. & Leydesdorff L. (2000): The dynamics of innovation: from National Systems and “Mode 2” to a Triple Helix of university-industry-government relations. Research Policy 29, pp. 109-123.

Fang C., Lee J., & Schilling M. A. (2010): Balancing exploration and exploitation through structural design: The isolation of subgroups and organizational learning. Organization Science, 21(3), pp. 625-642.

Freeman C. (1989): Technology Policy and Economic Performance: Lessons from Japan. London: Pinter Publishers.

Freeman C. (1991): Networks of innovators, a synthesis of research issues. Research Policy, 20, pp. 499-514.

Freeman C. (2002): Continental, national and sub-national innovation systems - complementarity and economic growth. Research Policy 31, pp. 191-211.

Fujigaki Y., & Leydesdorff L. (2000): Quality control and validation boundaries in a triple helix of university-industry-government: “Mode 2” and the future of university research. Social Science In-formation, 39(4), pp. 635-655.

Funtowicz S. O., & Ravetz J. R. (1993): The emergence of post-normal science. In Science, politics and morality (pp. 85-123). Springer Netherlands.

Gibbons M., Limoges C., Nowotny H., Schwartzman S., Scott P., Trow M. (1994): The new production of knowledge: The dynamics of science and research in contemporary societies. London: Sage.

Godin B., and Gingras, Y. (2000): The place of universities in the system of knowledge production. Research policy, 29(2), pp. 273-278.

Granovetter, M. (1973): The strength of weak ties. American Journal of Sociology, 78. pp. 1360–1380.

Grunwald A. (2015): Transformative Wissenschaft - eine neue Ordnung im Wissenschaftsbetrieb? GAIA-Ecological Perspectives for Science and Society 24(1), pp. 17-20.

Gulati R., Nohria N., & Zaheer A. (2000): Strategic networks. Strategic management journal, pp. 203-215.

Hagedoorn J. and Schakenraad J. (1989): Strategic partnering and technological cooperation'', in Dankbaar B., Groenewegen J. and Schenk H. (Eds.): Perspectives in Industrial Economics. Dordrecht: Kluwer.

Hagedoorn J. and Schakenraad J. (1990): Inter-firm partnerships and co-operative strategies in core technologies. In Freeman C. and Soete L. (Eds.): New Explorations in the Economics of technological Change. Pinter Pub Ltd.

Hakanson H. and Johanson J. (1988): Formal and informal cooperation strategies in international industrial networks. In Contractor F.J. and Lorange P. (Eds.): Cooperative Strategies in International Business. Lexington, MA: Lexington Books, pp. 369-79.

Hall P.A. and Gingerich D.W. (2009): Varieties of Capitalism and Institutional Complementarities in the Political Economy: An Empirical Analysis. B.J.Pol.S. 39, pp. 449-482.

Harris R. G. (2001): The knowledge-based economy: intellectual origins and new economic perspectives. International Journal of Management Reviews 3(1), pp. 21-40.

Hekkert M. P., Suurs R. A., Negro S. O., Kuhlmann S., Smits R. E. (2007): Functions of innovation systems: A new approach for analysing technological change. Technological forecasting and social change, 74(4), pp. 413-432.

Jacobsson S. and Johnson A. (2001): The diffusion of renewable energy technology: an analytical framework and key issues for research. Energy Policy 280, pp. 625–640.

Jacobsson S., Sanden B.A., Bangens L. (2004): Transforming the energy system – The evolution of the German Technological System for solar cells. Technological Analysis and Strategic Management 16(1), pp. 3-30.

Jacobsson S. and Bergek, A. (2004): Transforming the energy sector: the evolution of technological systems in renewable energy technology. Industrial and corporate change 13(5), pp. 815-849.

Jagger N. and Miles I. (1989): INFORMAL international collaboration in science: analysis of a survey conducted by ACOST. SPRU, University of Sussex, October.

Jarillo J. C. (1988): On strategic networks. Strategic management journal, 9(1), pp. 31-41.

Johnson A. (2001): Functions in Innovation System Approaches. Paper for the DRUID's Nelson Winter conference Aarlborg, Netherlands.

Kanter, R.M. (2000): When a Thousand Flowers Bloom: Structural, Collective, and Social Conditions for Innovation in Organization. Entrepreneurship: The Social Science View, pp. 167-210 2000. Ac-cessed April 6th 2017 at: https://ssrn.com/abstract=1512270

Keil M., & Carmel E. (1995): Customer-developer links in software development. Communications of the ACM, 38(5), pp. 33-44.

Kline S. J. and Rosenberg N. (1986): An overview of innovation. In Landau R. and Rosenberg N.: The positive sum strategy: Harnessing technology for economic growth. Washington DC: National Academy Press.

Lazer D., & Friedman A. (2007): The network structure of exploration and exploitation. Administrative Science Quarterly, 52(4), pp. 667-694.

Leydesdorff L., & Meyer M. (2006): Triple Helix indicators of knowledge-based innovation systems: Introduction to the special issue. Research policy 35(10), pp. 1441-1449.

Liu X., White S. (2001): Comparing innovation systems: a framework and application to China's transitional context. Research Policy 30, pp. 1091-1114.

Lundvall B. Å. (1992): National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning. London: Pinter.

Lundvall B. Å. and Johnson B.H. (1994): The Learning Economy. Journal of Industry Studies 1(2), pp. 23-42.

Lundvall B. Å. (2007): National innovation systems—analytical concept and development tool. Industry and innovation, 14(1), pp. 95-119.

Malerba F. (2002): Sectoral systems of innovation and production. Research policy, 31(2), 247-264.

Malerba F. (Ed.) (2004): Sectoral systems of innovation: concepts, issues and analyses of six major sectors in Europe. Cambridge: Cambridge University Press.

Malerba F. and Torrisi S. (1992): Internal capabilities and external networks in innovative activities. Evidence from the software industry. Econonomics of Innovovation and New Technology, 2, pp. 49-71.

McKelvey M. D. (1994): Evolutionary Innovation: Early Industrial Uses of Genetic Engineering. Linköping: Linköping Studies in Arts and Sciences.

Metcalfe J. S. (1995): Technology systems and technology policy in an evolutionary framework. Cambridge Journal of Economics 19(1), pp. 25-46.

Milgram S. (1967): The small world problem. Psychology Today, 2, pp. 60–67.

Mytelka L.K. (2001): Mergers, Acquisitions, and Inter-firm Technology Agreements in the Global Learning Economy. In: Archibugi D. and Lundvall B. Å. (eds.) (2001): The globalizing learning econo-my. New-York: Oxford University Press, pp. 127-144.

Nelson R. R. and Winter S.G. (1982): An Evolutionary Theory of Economic Change. Cambridge, MA: Belknap Press.

Nelson R. R. (Ed.) (1993): National innovation systems: a comparative analysis. Oxford: Oxford university press.

Nowotny H., Scott P., Gibbons M. (2003). Introduction: Mode 2'Revisited: The New Production of Knowledge. Minerva, 41(3), pp. 179-194.

Nowotny H., Scott P., & Gibbons M. (2006): Re-thinking science: mode 2 in societal context. Knowledge creation, diffusion, and use in innovation networks and knowledge clusters. A compar-ative systems approach across the United States, Europe and Asia, pp. 39-51.

Paci R., & Usai S. (1999): Externalities, knowledge spillovers and the spatial distribution of innovation. GeoJournal, 49(4), pp. 381-390.

Patel P. and Pavitt K. (1994): National Innovation Systems: Why they are important, and how they might be measured and compared. Economics of Innovation and New Technology (3)1, pp. 77-95.

Polanyi M. (1958): Personal Knowledge: Towards a Post-Critical Philosophy. London: Routledge and Kagin Paul.

Powell W. W., Koput K. W., & Smith-Doerr L. (1996): Interorganizational collaboration and the locus of innovation: Networks of learning in biotechnology. Administrative science quarterly, pp. 116-145.

Provan K. G., Fish A., & Sydow J. (2007): Interorganizational networks at the network level: A re-view of the empirical literature on whole networks. Journal of management, 33(3), pp. 479-516.

Pyka, A. (1997): Informal networking. Technovation, Vol. 17(4), 207-224.

Pyka A. (2002): Innovation networks in economics: from the incentive-based to the knowledge-based approaches. European Journal of Innovation Management, 5(3), pp. 152-163.

Pyka, A. (2014): Avoiding evolutionary inefficiencies in innovation networks. Prometheus, Vol.32 (3), 265-279.

Pyka, A. and Saviotti, P. (2005): The evolution of R&D networking in the biotech industries. International Journal of Entrepreneurship and Innovation Management, Vol. 5(1-2), 49-68.

Rosenberg N. (1976): Selection and Adaptation in the Transfer of Technology: Steam and Iron in America: 1800-1870. In Perspectives on Technology, Cambridge, UK: Cambridge Press.

Rothwell R. and Zegveld W. (1981): Industrial Innovation and Public Policy: Preparing for the 1980s and the 1990s. London: Pinter.

Sábato, J. A. (1975). El pensamiento latinoamericano en la problemática ciencia teconología desarrollo dependencia. Paidós , Buenos Aires.

Schäfer W. (2012). Finalization in science: the social orientation of scientific progress (Vol. 77). Springer Science & Business Media.

Schneidewind U., Singer-Brodowski M., Augenstein K., Stelzer F. (2016): Pledge for a transforma-tive science: A conceptual framework (No. 191). Wuppertal Papers.

Schot J. and Steinmueller W.E. (2016): Framing Innovation Policy for Transformative Change: Innovation Policy 3.0. Working paper of the Science Policy Research Unit (SPRU), University of Sussex.

Schumpeter J. (1942): Creative destruction. Capitalism, socialism and democracy, 825.

Van Der Valk T., & Gijsbers G. (2010): The use of social network analysis in innovation studies: Mapping actors and technologies. Innovation, 12(1), pp. 5-17.

Von Hippel E. (1989). Cooperation between rivals: informal know-how trading. In Carlsson B. (Ed.): Industrial Dynamics, Kluwer Academic Publishers.

Walker W. (2000): Entrapment in large technology systems: institutional commitment and power relations. Research Policy 29(7), pp. 833-846.

Watts D., Strogatz S. (1998): Collective dynamics of small-world networks. Letters to Nature, 393 , pp. 440–442.

Weingart P. (1997): From “Finalization” to “Mode 2”: old wine in new bottles?. Social science information, 36(4), pp. 591-613.