Universiteit Utrecht

Faculty of Geosciences
Copernicus Institute for Sustainable Development and Innovation

Understanding technological change

explanation of different perspectives on innovation and technological change

Marko Hekkert, Simona Negro

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1.THE LINEAR MODEL

One of the first (theoretical) frameworks developed for historically understanding science and technology and its relation to the economy has been the "linear model of innovation". The model postulates that innovation starts with basic research, then adds applied research and development, and ends with production and diffusion:

Basic research → Applied research → Development → (Production and) Diffusion

The model has been very influential. Academic organizations as a lobby for research funds, and neoclassical economists as expert advisors to policy makers, have disseminated the model, or the understanding based thereon, widely, and have justified government support to science using such a model. As a consequence, science policies carried a linear conception of innovation for many decades, as well as academics studying science and technology (Godin, 2006).

The linear model has been criticized for ignoring feedback loops, market signals, and iterative learning, and for over-narrowly equating research and development with innovation (Shapira, 2010). As claimed by N. Rosenberg and others (1994) "everybody knows that the linear model of innovation is dead" (Rosenberg, 1994).

2.THE SYSTEMIC NATURE OF INNOVATION

The modern view on innovation therefore goes beyond the linear model and stresses the complex character of innovation. The most important framework to understand the complete innovation process is the innovation system framework. It recognizes the complexity of innovation and stresses that firms normally do not innovate in isolation but collaborate with many other organizations and are also dependent on the actions of other organizations. These organizations can be other firms, government bodies, NGO's, universities, intermediary organizations and so on. Next to organizations, firms are also influenced by institutions which can be defined as the rules of the game. Generally, the literature distinguishes between formal and informal institutions. Formal institutions are regulations and laws while informal institutions are values, norms, shared expectations, routines and shared cognitive frames that influence the actions of organizations.
A formal definition of an Innovation System based on the definition by Freeman (1987) is the following: the networks of organizations and institutions in the public and private sectors whose activities and interactions initiate, import and diffuse new technologies. Another even broader definition by Edquist (1997) is "all important economic, social, political, organizational, institutional factors that influence the

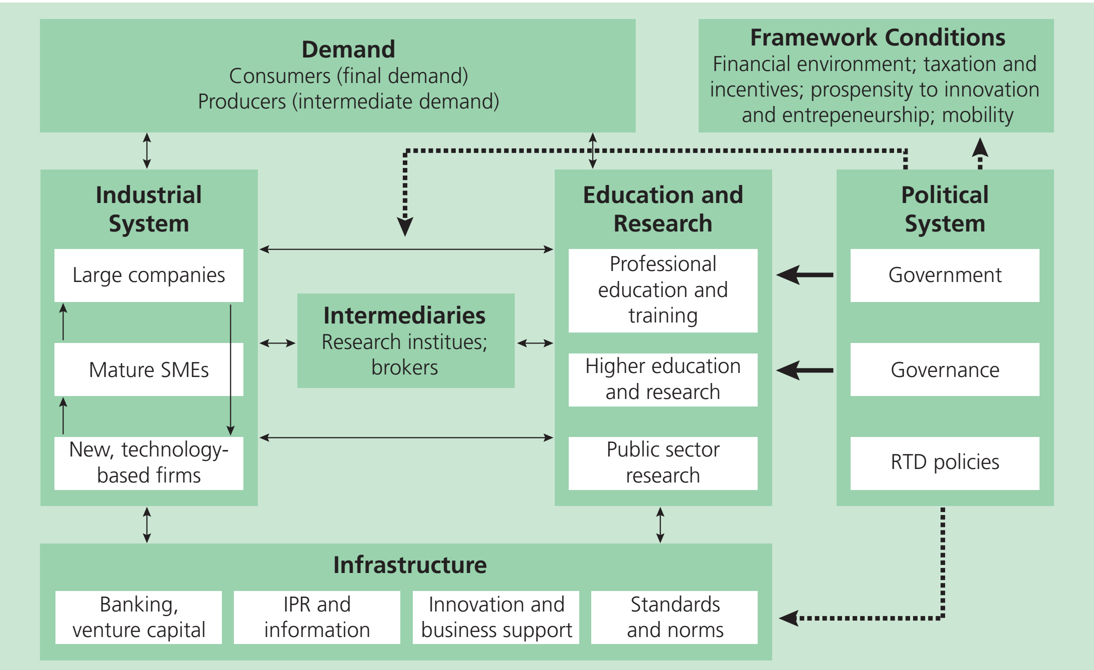

Figure 1 Kuhlman and Arnold, (2001)

development, diffusion and use of innovations". We do not subscribe such a very broad definition of innovation systems since it includes almost everything. What the definition clearly shows though is that innovating firms are embedded in a much wider socio-economic environment in which political and cultural influences as well as economic policies help to determine the scale, direction and relative success of innovation activities (Edquist, 2004a,Edquist, 2004b). The innovation model is not contradictory with the linear model. In fact, the stages defined in the linear model are real and important. However, the innovation systems framework highlights that these phases in innovation are influenced by a much wider environment in which the innovation process takes place and that due to this environment many feedback loops exist between the different phases.

Most authors on innovation systems agree that innovation systems consist of components and relations between the components. We distinguish between the following components: organizations, institutions (rules of the game) and physical infrastructures and technologies. These components and the interaction between these system components influence the outcome of innovation processes. Even though innovation systems share these main components, they differ in the type of organizations and institutions that make up the system.

Innovation systems can be mapped by analyzing which specific organizations, institutions and infrastructures make up the innovation system. Figure 1 presents a schema for the mapping of the organizations and institutions in an innovation system. We may call this the structure of the innovation system.

3. INNOVATION SYSTEM FUNCTIONING

A recent contribution to innovation systems theory is the recognition that a system does not only consist of components but in the eyes of an analyst or policy maker also has a function. The main function of an innovation system in the eyes of a policy maker or analyst is to develop and diffuse innovations. In general systems theory system's function is a normal part of systems theory. The concept of innovation systems however does not stem from general systems theory, instead it was developed by heterodox economists as an answer to the suboptimal view on innovation in neo-classical economics (linear model of innovation). The insights from general systems theory were added to the Innovation systems framework to address the fundamental weakness of the innovation system framework: the lack of system level explanatory factors (Liu and White, 2001). By just focusing on the structure of an innovation system, it is possible to analyze which organizations and institutions are present in an innovation system, but without the concept of system functions an analysis of the structure of the innovation system does not shed light on how an innovation system is functioning. Jacobsson and Johnson (2003) state that to support innovation, a number of functions have to be served within it. In the literature several sets of system functions are mentioned. We will describe the list that is often used by Utrecht researchers and that is quite close to the list used in the later work by Staffan Jacobsson and Anna Bergek of Chalmers University (Bergek et al., 2008).

Function 1: Entrepreneurial activities

There is no such thing as an innovation system without entrepreneurs. Entrepreneurs are essential for a well functioning innovation system. The role of the entrepreneur is to turn the potential of new knowledge, networks, and markets into concrete actions to generate – and take advantage of – new business opportunities. Entrepreneurs can be either new entrants that have the vision of business opportunities in new markets, or incumbent companies who diversify their business strategy to take advantage of new developments.

The entrepreneurs' risky experiments are necessary to cope with the large uncertainties that follow from new combinations of technological knowledge, applications and markets.[1] By experimenting, more knowledge can be collected about the functioning of the technology under different circumstances. Moreover, reactions of consumers, government, competitors, and suppliers can be evaluated. By experimenting, many forms of learning take place.

The presence of active entrepreneurs is a first and prime indication of the performance of an

1 This uncertainty is a fundamental feature of technological and industrial development. In (Meijer et al., 2006) a framework is presented regarding uncertainties in technological transitions. They distinguish between technological, resource, competitive, supplier, consumer, and political uncertainty.

innovation system. When entrepreneurial activity lags behind, causes may be found in the other six functions.

Function 2. Knowledge development
As mentioned above, mechanisms of learning are at the heart of any innovation process. For instance, according to Lundvall: "the most fundamental resource in the modern economy is knowledge and, accordingly, the most important process is learning" (Lundvall, 1992). Therefore, R&D and knowledge development are prerequisites within the innovation system. This function encompasses 'learning by searching' and 'learning by doing'.

Function 3. Knowledge diffusion through networks
According to Carlsson and Stanckiewicz (1991) the essential function of networks is the exchange of information. This is important in a strict R&D setting, but especially in a heterogeneous context where R&D meets government, competitors, and market. Here policy decisions (standards, long term targets) should be consistent with the latest technological insights and, at the same time, R&D agendas should be affected by changing norms and values. This way, network activity can be regarded as a precondition to 'learning by interacting'. When user producer networks are concerned, it can also be regarded as 'learning by using'.

Function 4. Guidance of the search
Since resources are almost always limited, it is important that, when various technological options exist, specific foci are chosen for further investments. Without this selection there will be insufficient resources left for the individual options. This function can be fulfilled by a variety of system components such as the industry, the government, and/or the market. When knowledge creation (function 2) is regarded as the creation of technological variety, this function represents the process of selection.
Also, from a societal stance, guidance of the search is an important activity. Where functions 2 and 3 referred to mechanisms of learning, without discussing the direction of the learning process, guidance of the search indicates that technological change is not autonomous. Changing preferences in society, if strong and visible, can influence R&D priority setting and thus the direction of technological change.
As a function, guidance of the search refers to those activities within the innovation system that can positively affect the visibility and clarity of specific wants among technology users.

Function 5. Market formation
New technology often has difficulty to compete with embedded technologies. Rosenberg (1976) puts it like this: "Most inventions are relatively crude and inefficient at the date when they are first recognized as constituting a new innovation. They are, of necessity, badly adapted to many of the ultimate uses to which they will eventually be put; therefore, they may offer only very small advantages, or perhaps none at all, over previously existing techniques. Diffusion under these circumstances will necessarily be slow" (Rosenberg, 1976). Because of this, it is important to create protected space for new technologies. One possibility is the formation of temporary niche markets (Schot et al., 1994) for specific applications of a technology. Within such an environment actors can learn about the new technology (function 2 and 3) and expectation can be developed (function 4). Another possibility is to create a (temporary) competitive advantage by favorable tax regimes (e.g., the Dutch experience with reducing taxes for renewable energy) or minimal consumption quotes (e.g., the German feed-in law for renewable energy).

Function 6. Resources mobilization
Resources, both financial and human capital, are necessary as a basic input to all activities within the innovation system. For a specific technology, the allocation of sufficient resources is necessary to make knowledge production possible. In this sense, this function can be regarded as an important input to function 2.

Function 7. Creation of legitimacy/ counteract resistance to change
In order to develop well, a new technology has to become part of an incumbent regime, or it even has to overthrow it. Parties with vested interests will often oppose to this force of 'creative destruction'. In that case, advocacy coalitions can function as a catalyst; they put a new technology on the agenda (function 4), lobby for resources (function 6) and favorable tax regimes (function 5), and by doing so create legitimacy for a new technological trajectory (Sabatier and Jenkinssmith, 1988). If successful, advocacy coalitions will grow in size and influence; they may become powerful enough to brisk up the

spirit of creative destruction. The scale and successes of these coalitions directly depend on the available resources (function 6) and the future expectations (function 4) associated with the new technology.

4. SYSTEMIC FAILURES/SYSTEMIC PROBLEMS

We have now focused on describing an innovation system in terms of its structural components and its functions. There is one more feature of innovation systems that is important. An innovation system can also be described in terms of systemic failures. These are problematic structures of the innovation system that prevent the system from functioning well.
Innovation systems analyses are especially useful for analyzing which systemic problems hamper the development and diffusion of innovations. In fact, since the introduction of Innovation Systems approach (e.g., (Edquist and Hommen, 1999)) system failures or system problems are defined as the new rationale for government interventions (Klein Woolthuis et al., 2005). System approaches are believed to have a greater potential for identifying where public support should go and to identify areas of systematically weak performance than the neoclassical perspective (Alkemade et al., 2011,Smith, 2000). Various authors have provided listings of possible systemic failures and problems. However in order for these categories of system problems to lead to policy interventions a clear link between the empirically observed problems in a certain domain and the conceptual categories of system problems is needed.
The literature described systemic problems as 'systemic failure' (OECD, 1997), 'weakness', 'imperfection' or 'problems' (Klein Woolthuis et al., 2005,Smith, 2000). Lipsey et al. (2005) argue that when technology changes endogenously and in conditions of uncertainty there is no optimality nor equilibrium, and so optimum allocation of resources or optimal policies are not possible. In such conditions it is impossible to talk about a *failure* or an 'imperfection' (Wieczorek, 2009). A weakness is equally inappropriate term in that context as a weakness is not necessarily a problem; a situation that needs action (Wieczorek, 2009). From now on we refer to these systemic failures, weaknesses or imperfections as ***systemic problems.*** *W*e thereby define systemic problems as "all systemic factors that block the operation and the development of innovation systems". Table 1 provides an overview of the categories of systemic problems identified in the literature (adapted from Wieczorek(2009)).

Our interpretation of the sets of systemic problems in literature is that the following set of systemic problems is conceptually the best one.

Market structure problems:
Market structure is defined as the organization of the current market and the criteria used to select innovations. A new technology may suffer from competing incumbent substitutes that have been able to undergo a process of increasing returns (Arthur, 1988). This tends to associate the new product with a high price (lack of scale and experience economies) or low utility (poor performance, lack of network externalities and/or infrastructure). If the gap is very large, and if there is a paucity of nursing (Erickson and Maitland, 1989) or bridging segments (Andersson and Jacobsson, 2000) that allow for a gradual generation of increasing returns, a new technology may never have the chance to rectify these initial disadvantages. Also, the selection processes in the market may not involve a 'free' choice by customers when the market is controlled by dominant incumbents (Jacobsson and Johnson, 2000). Also traditional market failures belong in this category.

Infrastructure problems (physical and knowledge):
Infrastructure is the basic physical and organizational structure needed for the operation of a society or enterprise or the services and facilities necessary for an economy to function. *Knowledge infrastructure* refers to both physical assets such as highly specialized buildings (laboratories and testing facilities) and equipment, as well as to non-physical assets related to scientific and applied knowledge. *Physical infrastructures* refer to the technical structures necessary for a society to function like electricity grids, natural gas grids, high-speed ICT infrastructure, and highway systems. Infrastructure problems are normally associated with the absence of necessary infrastructures for the new technological trajectory. Physical infrastructures usually play a large role in the transformation of large technical systems such as the energy system. Large investment costs and coordination problems associated with the build-up of a new infrastructure are a reason for government

Table 1 Overview of different systemic problems

Systemic problems	OECD 1997	Smith 2000	Jacobsson & Johnson 2000	Klein-Woolthuis et al 2005	Chaminade & Edquist 2007	Foxon& Pearson 2007	Mierlo et al 2010	Weber & Rohracher 2011
Hard & soft institutions	Mismatch between basic & applied research; Malfunctioning of the technology transfer institutions	Institutional failures	Legislative failures; Failures in educational system	Hard institutional failures; Soft institutional failures	Institutional problems (hard); Institutional problems (soft)		Institutional (hard); Institutional (soft)	Institutional failures
Market structures			Poorly articulated demand; economies of scale			Copy Knowledge; Negative Externalities	Market structure	
Capability problems	Information & absorptive deficiencies of enterprises			Capabilities' failure	Capability & learning problems		Capacities	
Knowledge & Physical infrastructure		Failures in infrastructural provision & investment		Infrastructural failures	Infrastructure provision & investment problems		Infrastructure (Knowledge); Infrastructure (Physical)	Failures in infrastructural provision & investment
Too weak & Too strong interactions	Lack of interaction between actors		Poor connectivity; Wrong guidance for future markets	Interaction failures: Strong network failures & Weak network failures	Network problems/ Unbalanced exploration-exploitation echanisms; Complimentarity problems		Interaction (too strong); Interaction (too weak)	
Transition failure		Transition failures			Transition problems			Adaptation failures
Lock-in		Lock-in failures	Local search processes		Lock in problems			Lock-in failures
Directional								Directional
Demand articulation								Demand articulation
Institutional coordination								Institutional coordination
Reflexivity								Reflexivity

intervention in these transformation processes (Klein Woolthuis et al., 2005).

Institutional problems (hard & soft):
Institutions form a key factor in innovation systems theory that envisages the institutional context as a defining and structuring element in the system, and institutional problems refer to the institutional mechanisms that may hinder innovation. *Hard institutions are* formal, written, consciously created institutions, e.g., technical standards, labor law, risk management rules etc. *Soft institutions* refer to informal, often evolved spontaneously and may be the implicit 'rules of the game', e.g., social norms and values, the legitimacy of new technology, culture, willingness to share resources with other actors, entrepreneurial spirit within organizations, industries, regions and countries and tendencies to trust, risk averseness. Taken together these institutions are conceptualized as the selection environment in which firms, knowledge institutes as well as the government itself are embedded (Klein Woolthuis et al., 2005).

Interaction problems (too strong & too weak):
Market relationships 'persist through time and involve inter-firm cooperation in the development and design of products' (Smith, 2000)(Klein Woolthuis et al., 2005). Interactions not only involve relationships with other firms but also the interaction with e.g. the government, public knowledge institutes, and third parties such as specialized consultants. Interaction problems can be caused by either too strong or too weak interactions. *Strong interaction problems* occur within a network when individual actors are guided in the

wrong direction by network actors and consequently fail to supply each other with the required knowledge or when the network is too closed and actors become reluctant to exit the group or let new entrants in. Actors may also be 'locked into' their relationships due to asset specificity, switching costs or due to lack of alternative partners. *Weak network failures* occur when the connectivity among complementary technologies and actors is poor, fruitful cycles of learning, adaptation to new technological developments and innovation are therefore prevented. Moreover, if organizations in a system interact poorly this may lead to a lack of shared vision of future technology developments, which in turn might hinder the coordination of research efforts and investment (Klein Woolthuis et al., 2005).

Capability problems:
Companies can simply lack the competences, capabilities or resources to make the leap from an old to a new technology or paradigm (Klein Woolthuis et al., 2005,Afuah and Utterback, 1997,Anderson and Tushman, 1990). With regard to search processes firms build upon their existing knowledge base and other assets when they search for new opportunities, therefore they may be ignorant of opportunities which are at some distance: their vision may also be 'bounded' (Jacobsson and Johnson, 2000).

5. DIFFERENT TYPES OF INNOVATION SYSTEMS

Now that we explained the basic features of innovations systems (definition, structure, functions and systemic problems) we will elaborate on the fact that literature makes a distinction between different types of innovation systems. Basically, three dimensions can be acknowledged that define the different types of innovation systems. These dimensions are the direct results of what a policy maker or analyst aims to explain: innovation in geographical regions (National and Regional Innovation Systems), innovation in industrial sectors (Sectoral Innovation Systems) or specific technological innovations (Technological Innovation Systems).
The notion of National Innovation System places a major emphasis on the role of Nation states, where the geographical boundaries of the Innovation System are fixed. Within these boundaries, country-specific factors influencing the innovative capabilities of national firms are studied (Edquist 1997). By using national boundaries, actors sharing a common culture, history, language, social and political institutions are identified (Edquist 1997). Thus, the focus of NIS is to identify the importance of interactions among many agents within a single country and the way in which they support learning which promotes innovation (Senker et al. 1998).
More recently, the Regional Innovation Systems (RIS) approach has been developed. The basic idea is similar to that of the NIS approach, except that, instead, the unit of analysis is a region (Cooke et al., 1997,Saxenian, 1991). The purpose of RIS studies is to assess the innovative performance of a region. A main contribution of RIS scholars is the observation that distance matters; that is, the geographical distance between actors has a significant effect on the region's innovative performance. RIS studies tend to be more micro-oriented, including analyses on the level of (networks of) firms and other organisations. This allows for a dynamic approach, and in fact, many RIS studies incorporate a historical dimension (Carlsson et al., 2002). The NIS and RIS approaches typically do not take into account a detailed analysis of technological innovation processes.

Sectoral Innovation Systems (SIS) are defined by Breschi and Malerba (1997) (p.131) as:"…the system (group) of firms developing and making a sector's products and generating and utilising a sector's technologies…" (Breschi and Malerba, 1997). The focus of SIS lies on agents and firms, putting much emphasis on non-market interactions and on the processes of transformation of the system (Malerba, 2002). Furthermore, it focuses on competitive relationships among firms by explicitly considering the role of selection environment, where the main concern lies on the overall dynamics in the population of firms active in a sector (Breschi and Malerba 1997). The boundaries for the SIS emerge from the specific conditions of each sector, by focusing on the sources of knowledge and on the role played by geographical space in the processes of knowledge transmission (Breschi and Malerba 1997).

In case of studying the dynamics of energy innovations, the major interest is to understand and analyse specific technological change. The appropriate Innovation System in this case is the Technological Innovation System (TIS). This concept enables to study the characteristics of the system associated with a specific emerging technology, to analyse its strengths and weaknesses as well as its dynamics, and to compare it with the system of an incumbent technology system (Jacobsson and Johnson, 2000). The regional or local dimension is included in this approach as well (Carlsson and Jacobsson, 1997). However, if the main concern is to understand technological change, the dynamics of the Innovation System need to be identified. On the national level, the dynamics are difficult to map, since the complexity of the National Innovation System is considerable, due to the vast amount of actors, network relations, and institutions (Hekkert et al., 2007). As a result, many authors studying and comparing National Innovation Systems, focus on its current structure, presenting a static description of the structure without focusing on mapping the functioning of innovation systems (Hekkert et al., 2007). Since the focus of the Technological Innovation System lies on a specific technology, it reduces the complexity of the system. This reduced complexity enables analysis of system functioning.

6. THE COMPARISON OF THE INNOVATION SYSTEM APPROACH TO OTHER APPROACHES

Now we explained the innovation systems framework and showed that a specific innovation system model is best suited to study specific technological change, we will now explain one other model that is useful for analyzing technological change. This so-called 'Multi Level Perspective' (MLP) is dominant in studies that focus on understanding technological transitions, since it studies the interactions between *niche-innovations* and existing *regimes*, situated in a broader macro environment (Verbong and Geels, 2007).

The macro-level is defined as the *social-technical landscape,* where technological trajectories are situated. It contains a set of heterogeneous factors, such as oil prices, economic growth, wars, broad political coalitions, culture, and environmental problems, and it acts as external structure or context for interactions of actors. A characteristic of this level is that it is slow in its response to trends and developments. Furthermore, it influences regime dynamics and niches (Verbong and Geels, 2007,Rotmans et al., 2001,Geels, 2002). The *socio-technical regime* forms the meso-level, which refers to rules enabling and constraining activities within communities (Geels 2002). The regime consists of three interlinked dimensions, according to Verbong and Geels (2007): a) a network of actors and social groups, b) formal normative and cognitive rules, and c) material and technical elements (Verbong and Geels, 2007). *Niches* form the micro level; the role of niches is further developed in the Strategic Niche Management (SNM) approach. This approach aims to understand how the process of technological development comes about, where it can be used as a research model to analyze historical case studies and as a policy tool to formulate suggestions for policy makers (Raven, 2005). Niches are the places where novelties emerge, since they act as 'incubation rooms', shielding new technologies from the mainstream market selection. As new technologies have a low price/performance ratio, protection is needed and can be provided by small networks of actors who are willing to invest in the development of new technologies. Within the niches, the most important processes are i) the building of social networks, ii) learning processes, and iii) the articulation of expectations to guide learning processes. As these processes can reinforce each other in the form of positive feedbacks, an internal momentum is created in the niche (Raven, 2005). The internal momentum in the niche is important, but it is not sufficient for a breakthrough (Geels and Raven 2006). For a breakthrough to occur, it is important that developments at all three levels (landscape, regime, and niche) are linked up, reinforcing each other (Rotmans et al. 2001; Geels 2002). In addition, changes at the level of regime and landscape need to occur, offering a 'window of opportunity' for the new technology to break out of the niche. However, this process does not occur at once, it needs to build up gradually by following trajectories of niche-accumulation, i.e. by experimentation, learning processes, adjustments, and reconfigurations in various niches (Geels 2002).

To summarise, the key point of the Multi Level Perspective is that transitions and system innovations occur through the interplay between dynamics at multiple levels. These are no processes of simple 'cause' and 'effect', but of 'circular causality' where system transformations come about when these processes link up and reinforce each other (Geels and Raven, 2006). Since the breakthrough of a new technology is expected to come from an accumulation of niches, the

Strategic Niche Management approach is applied to further investigate the role of niches (Raven 2005).
However, in the Multi Level Perspective, only niche internal processes are specified. Interactions between niche and regime are claimed to be important, yet the interactions are not specified in terms of processes. Thus, what is missing in the Multi Level Perspective approach is, first, a theory on the successful growth of a niche for it to become part of the regime. Second, what misses is insight into the key processes that influence the successful breakthrough of a niche into the regime. Finally, what we need is a theory that includes the interaction process between an innovation and the surrounding networks and institutions. The innovation system model does provide these theoretical handholds and is therefore best suited to study technological change in the energy sector.

REFERENCES

Afuah, A.N., Utterback, J.M., 1997. Responding to structural industry changes: a technological evolution perspective. Industrial and Corporate Change 6, 183-202.

Alkemade, F., Hekkert, M.P., Negro, S.O., 2011. Transition policy and innovation policy: Friends or foes? EIST 1, 125-129.

Anderson, P., Tushman, M.L., 1990. Technological Discontinuities and Dominant Designs: A Cyclical Model of Technological Change. Adm. Sci. Q. 35.

Andersson, B.A., Jacobsson, S., 2000. Monitoring and assessing technology choice: the case of solar cells. Energy Policy 28, 1037-1049.

Arthur, B., 1988. Competing technologies: an overview, in Dosi, G.e.a. (Ed.), Technical Change and Economic Theory. Francis Printer, London, pp. 590-607.

Bergek, A., Hekkert, M., Jacobsson, S., 2008. Functions in innovation systems: A framework for analysing energy system dynamics and identifying goals for system-building activities by enterpreneurs and policy makers, in Foxon, T. J., Koehler, J., Oughton, C. (Ed.), Innovation for a Low Carbon Economy: Economic, Institutional and Management Approaches. Edward Elgar, Cheltenham.

Bergek, A., Jacobsson, S., 2003. The Emergence of a Growth Industry: A Comparative Analysis of the German, Dutch and Swedish Wind Turbine Industries, in Metcalf, S., Cantner, U. (Eds.), Change, Transformation and Development. Physica/Springer, Heidelberg, pp. 197-228.

Breschi, S., Malerba, F., 1997. Sectoral Innovation Systems: Technological Regimes, Schumpeterian Dynamics, and Spatial Boundaries Ch 6, in Edquist, C. (Ed.), In Edquist, C. (Ed.): Systems of Innovation – Technologies, Institutions and Organizations. Pinter, London, pp. 130-156.

Carlsson, B., Jacobsson, S., 1997. Diversity Creation and Technological Systems: A Technology Policy Perspective Ch 12, in Edquist (Ed.), Sytems of Innovation; Technologies, Institutions and Organisations. Pinter, London.

Carlsson, B., Stankiewicz, R., 1991. On the nature, function and composition of technological systems. Journal of Evolutionary Economics, 93-118.

Carlsson, B., Jacobsson, S., Holmen, M., Rickne, A., 2002. Innovation systems: analytical and methodological issues. Research Policy 31, 233-245.

Cooke, P., Gomez Uranga, M., Etxebarria, G., 1997. Regional innovation systems: institutional and organisational dimensions. Research policy 26, 475-491.

Edquist, C., 2004b. Reflections on the systems of innovation approach. Science and Public Policy 31, 485-489.

Edquist, C., 2004a. The Systemic Nature of Innovation, in Fagerberg/Mowery/Nelson (Ed.), Systems of Innovation – Perspectives and Challenges, Oxford.

Edquist, C., 1997. Systems of Innovation; Technologies, Institutions and Organisations. Pinter, London.

Edquist, C., Hommen, L., 1999. Systems of innovation: theory and policy for the demand side. Technology in Society 21, 63-79.

Erickson, W.B., Maitland, I., 1989. Healthy industries and public policy, in Dutton, M.E. (Ed.), Industry Vitalization. Pergamon Press, New York.

Freeman, C., 1987. Technology Policy and Economic Performance – Lessons from Japan. Pinter.

Geels, F.W., Raven, R., 2006. Non-linearity and Expectation in Niche-Development Trajectories: Ups and Downs in Dutch Biogas Development (1973-2003). Technology Analysis & Strategic Management 18, 375-392.

Geels, F.W., 2002. Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. Research Policy 31, 1257-1274.

Godin, B., 2006. The Linear Model of Innovation: The historical construction of an analytical framework. Science Technology Human Values %R 10.1177/0162243906296854 31, 639-667.

Hekkert, M.P., Suurs, R.A.A., Negro, S.O., Kuhlmann, S., Smits, R. E. H. M., 2007. Functions of innovation systems: A new approach for analysing technological change. Technological Forecasting and Social Change 74, 413-432.

Jacobsson, S., Johnson, A., 2000. The diffusion of renewable energy technology: an analytical framework and key issues for research. Energy Policy 28, 625-640.

Klein Woolthuis, R., Lankhuizen, M., Gilsing, V., 2005. A system failure framework for innovation policy design. Technovation 25, 609-619.

Kuhlmann, S., Arnold, E., 2001. RCN in the Norwegian Research and Innovation System.

Lipsey, R.G., Carlaw, K., Bekar, C., 2005. Economic Transformations: General Purpose Technologies and Long-Term Economic Growth. Oxford University Press, USA.

Liu, X., White, S., 2001. Comparing Innovation Systems: a framework and application to China's transitional context. Research Policy 30, 1091-1114.

Lundvall, B.-., 1992. Introduction, in Lundvall, B.-. (Ed.), National Systems of Innovation – Toward a Theory of Innovation and Interactive Learning. Pinter, London, pp. pp. 1-19.

Malerba, F., 2002. Sectoral systems of innovation and production. Research Policy 31, 247-264.

Meijer, I.S.M., Hekkert, M.P., Faber, J., Smits, R.E.H.M., 2006. Perceived uncertainties regarding socio-technological transformations: towards a framework. International Journal Foresight and Innovation Policy 2.

OECD, 1997. National Innovation Systems.

Raven, R., 2005. Strategic Niche Management for Biomass – A comparative study on the experimental introduction of bioenergy technologies in the Netherlands and Denmark. Eindhoven University, The Netherlands.

Rosenberg, N., 1994. Exploring the Black Box: Technology, Economics and History. Cambridge University Press, New York.

Rosenberg, N., 1976. Perspectives on Technology. Cambridge University Press, Cambridge.

Rotmans, J., Kemp, R., Van Asselt, M., 2001. More evolution than revolution: Transition management in public policy. Foresight 3, 15-31.

Sabatier, P.A., Jenkinssmith, H.C., 1988. Policy Change and Policy Oriented Learning – Exploring an Advocacy Coalition Framework – Introduction. Policy Sciences 21, 123-127.

Saxenian, A., 1991. The origins and dynamics of production networks in Silicon Valley. Research Policy 20, 423-437.

Schot, J., Hoogma, R., Elzen, B., 1994. Strategies for shifting technological systems – The case of automobile system. Futures 26, 1060-1076.

Shapira, P., 2010. Innovation and Small and Midsize Enterprises: Innovation Dynamics and Policy Strategies, in Smits, R.E.H.M., Kuhlmann, S., Shapira, P. (Eds.), the Theory and Practice of Innovation Policy – an International Research Handbook. Edward Elgar, Cheltenham, UK.

Smith, K., 2000. Innovation as a Systemic Phenomenon: Rethinking the Role of Policy. Enterprise & Innovation Management Studies 1, 73-102.

Verbong, G., Geels, F., 2007. The ongoing energy transition: Lessons from a socio-technical, multi-level analysis of the Dutch electricity system (1960-2004). Energy Policy 35, 1025-1037.

Wieczorek, A.J., 2009. A systemic policy framework. Methodological considerations. Paper presented at the 1st International Conference on Sustainability Transitions, Amsterdam, June 2009.

Utrecht University
Faculty of Geosciences

Heidelberglaan 2
3584 CS Utrecht

P.O. Box 80115
3508 TC Utrecht
The Netherlands

+31 (0)30 253 20 44

www.uu.nl/geo