Chapter 9

MULTI-LEVEL PERSPECTIVE ON SYSTEM INNOVATION: RELEVANCE FOR INDUSTRIAL TRANSFORMATION

Frank W. Geels
Department of Technology Management, Eindhoven University of Technology, IPO 2.10, 5600 MB Eindhoven, the Netherlands[*]

Abstract: This chapter describes how insights from several different disciplines can be integrated in a multi-level perspective, so as to contribute to an encompassing understanding of the dynamics of system innovation. The chapter also argues that a range of different policy instruments is needed to stimulate system innovations, and positions them in different phases and on different levels. Interesting topics for further research are also identified.

Key words: system innovation, multi-level perspective, policy implications, research agenda

1. INTRODUCTION

The aim of this paper is to present an integrative conceptual perspective on the dynamics of system innovations. An understanding of such dynamics is important, because system innovations have recently received much attention in environmental sustainability debates. Modern societies face structural problems in several sectors. Agriculture, for instance, suffers from the consequences of (over-) intensive production systems, such as manure problems, ammonia emissions, and diseases like Bovine Spongiform

[*] e-mail: f.w.geels@tm.tue.nl

Xander Olshoorn and Anna J. Wieczorek, Understanding Industrial Transformation: Views from Different Disciplines 163–186.

Encephalopathy (BSE[22]) and 'Foot & Mouth'. In the energy sector there are problems such as oil dependency, reliability, and CO_2 and NO_x emissions. In the transport system there are problems of congestion, energy use, and CO_2 emissions and air pollution (particulate matter, NO_x). These problems are deeply rooted in societal structures and activities. To solve them the Industrial Transformation (IT) project of the International Human Dimension Programme (IHDP) argues that system changes are needed (Vellinga and Herb, 1999). Several other recent contributions to the sustainability debate also propose widening the analytical focus from cleaner artefacts to cleaner systems (*e.g*. Unruh, 2000; Jacobsson and Johnson, 2000; Berkhout, 2002).

In the Dutch fourth National Environmental Policy Plan (VROM, 2001), the need for system changes has been rephrased as a need for transitions and system innovations. Substantial improvements in environmental efficiency (factor 2) may still be possible with incremental innovation and system optimisation. But large jumps in environmental efficiency (factor 10) may require system innovations and transitions. The promise of system innovations is represented in Figure 1.

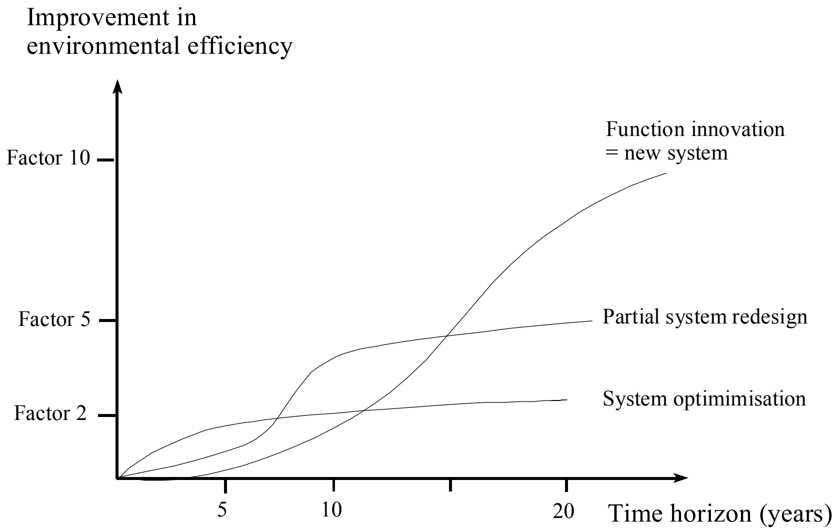

Figure 1. Environmental efficiency and system innovation (Weterings et al., 1997: 18)

System innovations are not merely about changes in technical products, but also about policy, user practices, infrastructure, industry structures and

[22] Bovine Spongiform Encephalopathy (BSE) or mad cow disease.

symbolic meaning, *etc*. To highlight that social and technical aspects are strongly interlinked, I propose to rephrase system innovations as changes from one socio-technical system to another. Figure 2 gives an example of a socio-technical system in the transport domain.

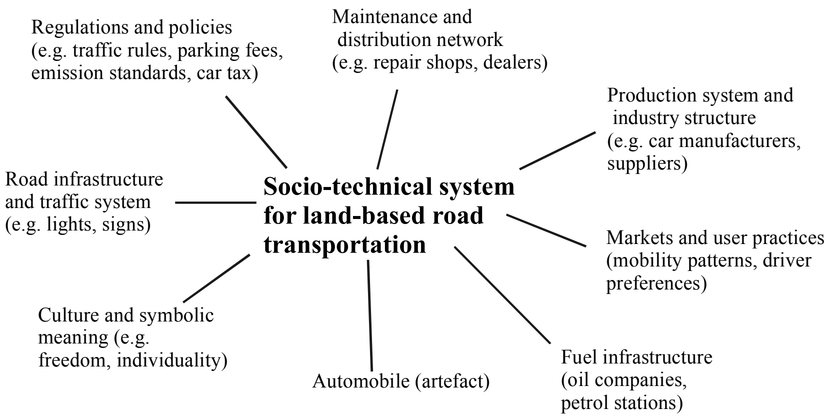

Figure 2. Illustration of the socio-technical transport system

The elements of socio-technical systems do not function on their own, but are actively created and maintained by human actors embedded in social groups. Figure 3 presents a stylised representation of some of the relevant groups in modern western societies.

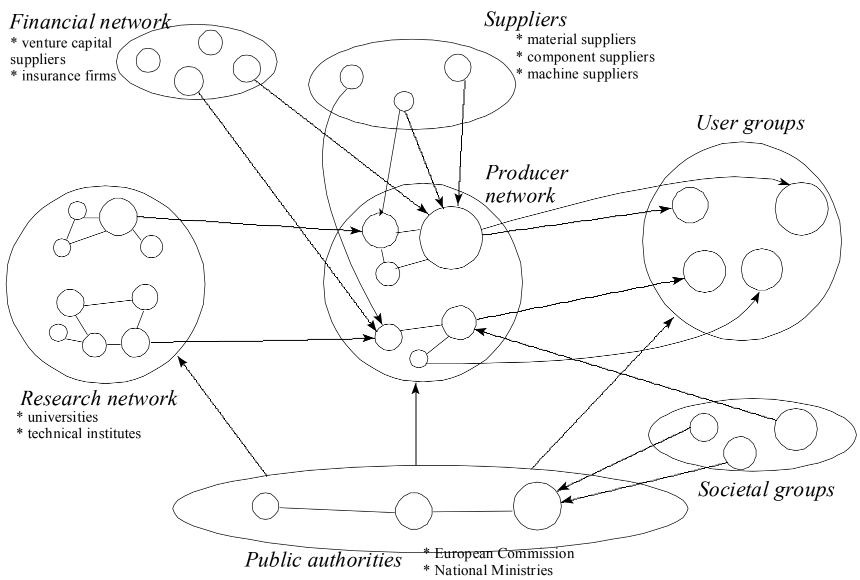

Figure 3. Social groups which (re-)produce socio-technical systems (Geels, 2002a: 1260)

System innovations can be delineated as having the following characteristics:

- They involve co-evolution of a number of related elements;
- They involve changes in the supply side (*e.g.* technology, knowledge, industry structures) *and* the demand side (user preferences, cultural meaning, infrastructure);
- They involve a wide range of actors;
- They are long-term processes (evolving over decades). This presents challenges for effective and consistent policy interventions over political timescales, and also for the analysis of ongoing transitions under policy interventions.

Because of the 'sustainability promise,' there is increasing interest in transitions and system innovations from policy-makers, NGOs, large firms and others. The Stockholm Environment Institute, for instance, published a book on the '*Great Transition'* (Raskin *et al.*, 2002). The American National Research Council (NRC, 1999) and the Dutch Research Council NWO have made transitions part of their research portfolio, and the IHDP bundles research across the world by funding a science programme on industrial transformation.

Although there is apparent interest from policy makers in system innovations, there is little systematic knowledge about transitions from one system to another. The main question this chapter aims to answer is: how do system innovations come about? As an answer to this question, the chapter describes a so-called multi-level perspective, in Section 3. This perspective was built on insights from other disciplines. To indicate these backgrounds, some of the building blocks are described in Section 2. Unfortunately, there is not enough space to describe precisely how these building blocks add up to the multi-level perspective (see Geels, 2004), but I will make brief references to the building blocks in Section 3. There is also insufficient space to give empirical examples, although references are provided to empirical work. The paper does address policy suggestions from this perspective (Section 4) and suggests a research agenda (Section 5).

2. SOME DISCIPLINARY BUILDING BLOCKS

Interesting insights can be found in a range of disciplines (see other chapters in this book). Particular elements from the literature can be used as building blocks for a more integrative perspective. This section briefly describes some of these building blocks. The description is eclectic and cannot do justice to all that has happened in different disciplines.

Sociology of technology

Sociology of technology highlights the notion that technologies are not simply there, but are actively constructed by human actors and social groups. Scholars in this discipline focus mainly on emerging technologies. Early in the development of a technology, there is much flux and uncertainty about precise technical characteristics, functional dimensions, markets and user preferences. Gradually, these dimensions become aligned and stabilise, leading to dominant designs and normal markets. Technologies, markets, user preferences, *etc*., are thus seen as the outcome of articulation processes, learning and interaction. Within this discipline there are several research streams with different point of emphasis. I will provide some brief descriptions.

In the social construction of technology approach (SCOT) the focus is on socio-cognitive processes, *i.e*., on giving meaning and interpreting in social groups (Pinch and Bijker, 1987; Bijker, 1995). The main aim of the SCOT approach is to understand the form and function of new technologies. Why do new technologies stabilise into a particular form, and how are they used? To answer this question, the SCOT approach studies the ideas and discourse about technological artefacts (*e.g*. problem agendas, search heuristics, guiding principles) in the social groups that are involved in the development and use of those technological artefacts, *e.g*. engineers, users, policy makers, social groups, *etc*. There is variation in the sense that different groups have different ideas and propose different solutions, but gradually one idea and solution become dominant, leading to consensus about the dominant meaning of an artefact. Selection is thus seen as a socio-cognitive process (closure and stabilisation of one interpretation in social groups).

In the socio-technical approaches of large technical systems (LTS) and actor-network theory (ANT), the focus is on linkages in and around the emerging technology. In both perspectives the dynamic is that heterogeneous elements are gradually linked together, emphasising co-evolution.

In LTS-research the focus is on (somewhat heroic) system-builders, who weave heterogeneous elements into a working system (Hughes, 1987; 1994; Mayntz and Hughes, 1988; Staudenmaier, 1989). System-builders such as Edison are ‘heterogeneous engineers.’ These engineers work not only on physical materials, but also on people, texts, devices, city councils, economics *etc*. Hughes (1987) coined the term ‘seamless web’ to indicate the heterogeneous character of LTS. In the early phases, the web is fragile, requiring system-builders to put in much work to uphold it. For example, as the electricity network grows and stabilises, it gains ‘momentum’ and begins to have coordinating effects (Hughes, 1994).

The perspective of socio-technical linkages is most consistently developed in ANT (Latour, 1987; 1991; Callon, 1991). New technologies emerge from a start as heterogeneous configurations. In the early phase of a new technology, the network consists of only a few elements and linkages. Innovation is about the accumulation of elements and linking them together in a working configuration. To achieve this, actors try to 'enrol' others, thus widening the network. They also try to 'translate' others, *i.e.*, assign them to particular roles and manipulate them into positions that suit their own purposes. In the ANT approach, enrolment and translation involve both human and non-human actors, leading to deep ontological debates that go beyond the purpose of this chapter. As the network is expanded and more elements are tied together, a technology 'becomes more real.' Diffusion is also a process of creating socio-technical linkages. The diffusion of an artefact across time and space needs to be accompanied by an expansion of linkages within which the artefact can function, *e.g.* test apparatus, spare parts, maintenance networks, and infrastructure. 'Thousands of people are at work, hundreds of thousands of new actors are mobilised' (Latour, 1987: 135).

A fourth stream in the sociology of technology highlights the importance of expectations and strategic visions of the future. Shared ideas about the future guide the direction of search activities. These visions can also be used by product champions as a strategic resource to attract attention (and funding) from other actors (Van Lente, 1993; Brown and Michael, 2003).

A fifth stream is formed by domestication studies. These look more closely at the demand for new technologies (*e.g.* products), arguing that the use of a technology involves more than simple adoption. New technologies have to be 'tamed' to fit into concrete routines and application contexts (including existing artefacts). Domestication involves symbolic and practical work, in which users integrate the artefact in their user practices and cognitive work, which includes learning about the artefact (Lie and Sørensen, 1996). This means that consumption and adoption are themselves acts of innovation. As users become acquainted with new artefacts, they may develop new user routines and new functionalities.

Business studies

In recent years, there has been increasing interest from business studies in radical product innovations, particularly because it was found that existing firms often 'wiped out' of the market because they did not foresee the next technological wave (Christensen, 1997). Some recent business studies emphasise that the co-evolution of technology and markets is a highly uncertain process, marked by setbacks and surprises, and with no guarantee of success (*e.g.* Lynn *et al*, 1996; Leonard-Barton, 1995). Firms that successfully navigated radical innovations engaged in various market experiments with technical prototypes during the early phases of development. Probing and learning was initially more important than immediate success.

These companies developed their products by probing initial markets with early versions of the products, learning from the probes, and probing again. In effect, they ran a series of market experiments, introducing prototypes into a variety of market segments (Lynn *et al.*, 1996: 15).

Evolutionary economics

Evolutionary economics (EE) is a very wide field, which I cannot do justice to here (see the chapter by Van den Bergh in this book). Many studies have a primary focus on firms and economic development. Attention on technology is then secondary and is only used to help explain economic performance. Those studies have limited relevance for my research question. But other EE studies take technological change as a focus in its own right. For instance, Nelson and Winter (1982) and Dosi (1982) consider seriously engineers' and designers' activities. Nelson and Winter (1982) argue that human beings use cognitive frameworks and routines to make sense of the world and guide activities. The search activities of engineers are guided by cognitive heuristics; that is, instead of exhaustively searching in all possible directions, engineers and R&D managers typically expect to find better results in certain directions. In so far as firms differ in their organisational and cognitive routines, there is variation in their technological search directions and the resulting products. The products (and the underlying routines and the firms which carry them) are selected in markets. Successful products (and firms) continue their routines, while less successful firms die out. When different firms share particular routines, these routines make up a *technological regime*, which leads to technical trajectories on a sectoral level. Technological regimes create stability because they provide a direction for incremental technical development.

Institutional theory

Institutional approaches highlight the point that human actors are embedded in social groups, and that the activities of social groups are coordinated by institutions. Institutions are often confused with (public) organisations (Scott, 1995). To avoid this confusion, the general concept of 'rules' also tends to be used. The function of institutions or rules is to guide (but not determine) the perceptions and activities of actors. Shared rules thus provide co-ordination and stability. Following Scott (1995), one can distinguish three kinds of rules: regulative, normative and cognitive. The *regulative* dimension refers to explicit, formal rules, *e.g.* government regulations, which structure the economic process through rewards, incentive structures and sanctions. Examples are property rights, contracts, patent laws, tax structures, trade laws and legal systems. These rules are often highlighted by institutional economists (*e.g.* Hodgson, 1998; North, 1990). *Normative* rules are often highlighted by traditional sociologists (*e.g.* Parsons, 1937). These rules confer values, norms, role expectations, duties, rights and responsibilities. Sociologists argue that such rules are internalised through socialisation processes. *Cognitive* rules constitute the perception of reality and the cognitive frames through which meaning is made. Social and cognitive psychologists have focused on the limited cognitive capacities of human beings and how individuals use schemas, frames, cognitive frameworks or belief systems to select and process information. Evolutionary economists and sociologists of technology have highlighted cognitive routines, search heuristics, exemplars, technological paradigms and the technological frames of engineers in firms and technical communities (see above).

Rules do not exist as single autonomous entities. Instead, they are linked together and organised into social rule *systems* or rule regimes (Burns and Flam, 1987). Regimes are thus semi-coherent sets of rules that are linked together, and it is difficult to change one rule without altering others. The alignment among rules gives a regime stability and ‘strength’ to coordinate activities.

In this section some interesting insights from different disciplines have been briefly discussed. The next section aims to describe an overarching conceptual perspective that combines or situates these insights with regard to each other.

3. A MULTI-LEVEL PERSPECTIVE ON SYSTEM INNOVATIONS

Both evolutionary economists and institutional theorists argue that socio-technical systems are stabilised by regimes that coordinate the activities of actors and social groups. This stabilising force creates inertia, lock-in and path dependence in existing systems. So it is an intriguing question how transitions to a new system take place.

An answer to this question is provided by the multi-level perspective (MLP) (Kemp, 1994; Schot *et al.*, 1994; Rip and Kemp, 1998; Kemp, *et al.*, 2001; Geels, 2002a; 2002b). The MLP distinguishes three levels: meso, micro and macro, which are not ontological descriptions of 'reality,' but analytical and heuristic concepts to understand system innovations.

The *meso-level* is formed by *socio-technical regimes*. This concept builds on Nelson and Winter's (1982) 'technological regimes', but is wider in two respects. First, while Nelson and Winter refer to cognitive routines, the MLP regime concept refers to the wider category of 'rules':

A technological regime is the rule-set or grammar embedded in a complex of engineering practices, production process technologies, product characteristics, skills and procedures, ways of handling relevant artefacts and persons, ways of defining problems; all of them embedded in institutions and infrastructures (Rip and Kemp, 1998: 340).

While the cognitive routines of Nelson and Winter are embedded in the practices and minds of engineers, regime-rules are embedded more widely. Second, socio-technical regimes not only refer to the social group of engineers and production firms, but also to other social groups. Socio-technical systems are actively created and maintained by several social groups (see above). Each of these social groups has its own distinctive features and its own 'selection' environment and therefore each has relative autonomy. At the same time, the groups are also interdependent and interact with each other. Interdependence and linkage between sub-systems occurs because activities of social groups are coordinated and aligned with each other. This is represented with the concept of socio-technical regimes. By providing orientation and co-ordination to the activities of relevant actor groups, socio-technical regimes account for the 'dynamic stability' of socio-technical systems. It is dynamic because innovation still occurs, but it is stable because innovations are of an incremental nature, going in predictable directions, leading to 'technical trajectories.' In evolutionary terms, socio-technical regimes function as a selection and retention mechanism. The rules in socio-technical regimes provide stability by guiding the perceptions and actions of actors. Rules can thus be characterised as the 'deep structure' or 'grammar' of socio-technical systems. In a similar fashion, Nelson and Winter (1982: 134) referred to routines as 'genes' of technological development.

The *micro-level* is formed by *technological niches*, the locus for radical innovations ('variation'). Because the performance of radical novelties is initially low, they emerge in 'protected spaces' to shield them from mainstream market selection. Niches thus act as 'incubation rooms' for radical novelties (Schot, 1998). Protection may occur in different forms. One form is within companies, *e.g.* as strategic R&D investments. Governments may add to the protection through R&D subsidies. Another form of protection is through subsidised real-life projects or experiments. This means stepping out from the laboratory into the wider world. These experiments involve a wide range of actors, *e.g*. firms, users, suppliers, universities, local and national authorities, and funding agencies. A third kind of protection is provided by special market niches, with special-performance selection criteria.

Niches are locations where it is possible to deviate from the rules in the existing regime. Hence, the emergence of new paths has been described as a 'process of mindful deviation' (Garud and Karnøe, 2001), and niches provide the locus for this process. This means that rules in technological niches are not as articulated or clear-cut. There may be uncertainty about technical design rules, user preferences or infrastructure requirements, *etc*. Niches provide space to learn about these dimensions. Insights from the sociology of technology and business studies are relevant here, *e.g*. experimentation, learning on many dimensions, interactions between multiple social groups, negotiations about meanings and interpretation. Niches provide space to build the social networks that support innovations. Product champions try to build constituencies around new innovations (Molina, 1995), trying to expand the network of linkages in which these innovations can function. Future visions and expectations are used as resources to enrol other actors. These visions will be gradually refined through experiences from learning processes. Learning, network building and vision articulation are internal niche processes that have been analysed and described under the label of strategic niche management (Kemp *et al.*, 1998; Kemp *et al.*, 2001; Hoogma *et al.*, 2002).

The *macro-level* is formed by the *socio-technical landscape,* which refers to aspects of the wider exogenous environment, which affect socio-technical development (*e.g*. globalisation, environmental problems, cultural changes). The metaphor 'landscape' is used because of the literal connotation of 'hardness' and to include the material aspect of society, *e.g*. the material and spatial arrangements of cities, factories, highways, and electricity infrastructures. Landscapes form 'gradients' for action; they are beyond the direct influence of actors in the regime, and cannot be changed at will. The French historian Braudel (1958) coined the term '*la longue durée*' for such long-term structural backdrops of society. At this level, we can also refer to long-wave theories that highlight long-term changes in the entire economy. Economic growth and prices seem to follow long-waves of 50-60 year cycles (Freeman and Perez, 1988).

The relationship among the three concepts can be understood as a nested hierarchy, meaning that regimes are embedded within landscapes and niches within regimes (see Figure 4). The work in niches is often geared to the problems of existing regimes (hence the arrows in the figure). Actors support the niche hoping that novelties will eventually be used in the regime or even replace it. This is not easy, because the existing regime is entrenched in many ways (*e.g*. institutionally, organisationally, economically, culturally). Radical novelties may have a 'mismatch' with the existing regime (Freeman and Perez, 1988), and do not easily break through. Nevertheless, niches are crucial for system innovations, because they provide the seeds for change.

I will now describe how the three levels interact dynamically over time, and how this interaction results in transitions and system innovations. The dynamics will be described in four phases (see also Rotmans *et al.*, 2001).

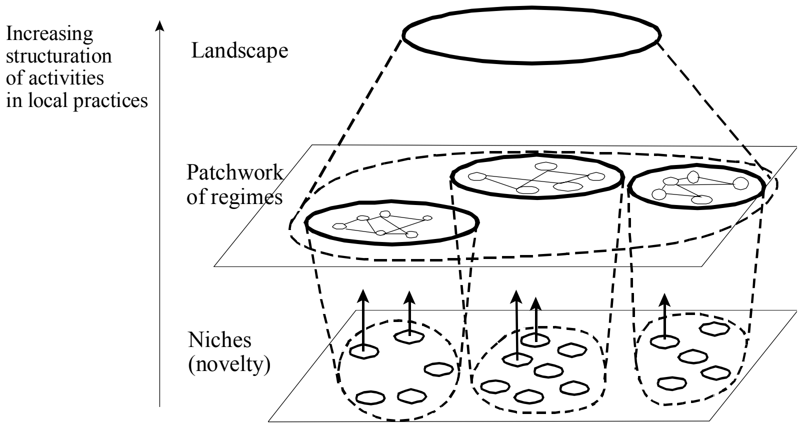

Figure 4. Multiple levels as a nested hierarchy (Geels, 2002a)

In the *first phase*, novelties emerge in niches in the context of problems in the existing landscape and regime. Both technical form and ideas about functionality are strongly shaped by the existing regime. There is not yet a dominant design, and there may be various technical forms competing with each other. Actors engage in experiments to work out the best design and find out what users want. The SCOT-approach highlights socio-cognitive processes and learning about meaning in social groups. Interpretative flexibility diminishes as consensus emerges about the dominant meaning of an artefact. LTS-approaches highlight product champions and system builders who weave heterogeneous elements into a working system. ANT-approaches emphasise how actors try to enrol each other to support innovations. They also show how new technologies, markets, user preferences and regulations shape each other as part of a translation and linkage process.

In the *second phase* the novelty is used in small market niches that provide resources for technical specialisation and exploration of new functionalities. Gradually, a dedicated community of engineers and producers emerges, directing their activities to the improvement of the new technology. They meet at conferences and discuss problem agendas, promising findings and search heuristics. Engineers gradually develop new rules, and the new technology develops a technical trajectory of its own. The new technology gradually improves as a result of learning processes. As users interact with the new technology and incorporate it into their practices, they build experience with it and gradually explore its new functionalities. This second phase results in a stabilisation of rules, *e.g.* a dominant design and articulation of user preferences.

The *third phase* is characterised by wide diffusion, breakthrough of new technology and competition with the established regime. There are two complementary explanations that can be used to explain the dynamics in this phase: external circumstances and internal 'drivers.'

External circumstances

The multi-level perspective highlights the point that breakthrough of novelties from the niche-level depends on niche-external circumstances at the regime and landscape level. Only if conditions in relating regimes and landscapes are simultaneously favourable will wide diffusion of the novelty occur. Such situations are called windows of opportunity. The following circumstances are important for windows of opportunity to arise: *(i)* internal technical problems in the regime, which cannot be met with the available technology; *(ii)* problems external to the system, negative externalities; *(iii)* stricter regulations, often in reaction to negative externalities; *(iv)* changing user preferences, which may lead to new markets with which new technologies may link; and *(v)* landscape changes that put pressure on the regime.

Internal 'drivers'

Besides such external circumstances at the regime level, there are also internal 'drivers' that stimulate diffusion of innovations. Disciplinary perspectives highlight different aspects.

– Economic: Improvements in cost/performance ratios stimulate wider diffusion. The performance of the new technology may be improved, as producers gain experience, *e.g.* learning by doing (Arrow, 1962). And there may be 'increasing returns to adoption' as highlighted by economic path dependence theorists[23];

– Socio-technical: In LTS- and ANT-approaches, the focus is on linkages in and around the emerging technology, and the activities of different actor-groups. The new configuration becomes more stable as more elements are linked together (*e.g*. technology, user practices, infrastructure, maintenance networks, regulations). The new system gains 'momentum' as more social groups have a vested interest in it;

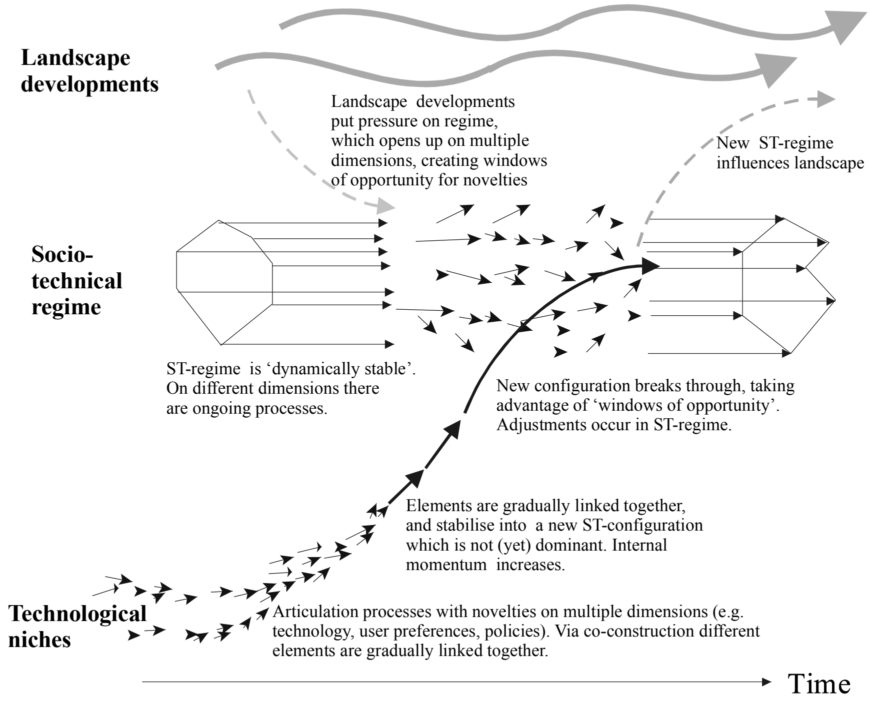

Figure 5. A dynamic multi-level perspective on system innovations (Geels, 2002b: 110)

[23] Arthur (1988: 591) identified five sources of increasing returns to adoption: *(i)* learning by using: the more a technology is used, the more is learned about it, the more it is improved; *(ii)* network externalities: the more a technology is used by other users, the larger the availability and variety of (related) products that come available and are adapted to the product use; *(iii)* scale economies in production, allowing the price per unit to go down; *(iv)* informational increasing returns: the more a technology is used, the more is known among users; *(v)* technological interrelatedness: the more a technology is used, the more complementary technologies are developed.

- Sociological: In the sociological literature (as in some business studies) the focus is on actors, organisations, groups and their perceptions, and (strategic) activities. All kinds of social mechanisms may accelerate or delay diffusion, *e.g*. hype and bandwagon effects, social struggles, effect of outsiders and strategic games, and the 'sailing ship effect.'[24]

In sum, the breakthrough of radical innovations depends both on internal drivers and niche-processes *and* on external developments in regimes and landscapes. The key insight of the multi-level perspective is that system innovations come about because developments at multiple levels link together and reinforce each other (see Figure 5). This means that system innovations are *not* caused by a change in a single factor or 'driver,' but are the result of the interplay of many processes and actors.

As the new innovation enters mainstream markets it begins a competitive relationship with the established regime. Economic considerations play an important role by instituting comparisons with regard to price and performance. From domestication and cultural studies, we know that the wide adoption of new technologies requires efforts by users to domesticate and integrate new technologies into their user practices. This may involve symbolic work, practical work and cognitive work by the users. Changes in user practices may lead to the articulation of new functionalities. Eventually, a new regime is formed, and a period of relative stability sets in.

In the fourth phase the new technology replaces the old regime, which is accompanied by changes in wider dimensions of the socio-technical regime. This often happens in a gradual fashion, because the creation of a new socio-technical regime takes time, *viz*. new infrastructures, new user practices, new policies. Furthermore, incumbents tend to stick to old technologies because of vested interests and sunk investments. They may also try to defend themselves, *e.g*. by improving the existing technology (sailing ship effect), political lobbying or evasion to other markets. The new regime may eventually also influence wider landscape developments. An example is the transition from sailing ships to steamships, which contributed to the expansion of worldwide trade, as freight tariffs went down. The importing of large quantities of cheap grain in Europe changed feeding patterns and raised standards of living and health, but it also threatened the livelihood of

[24] The sailing ship effect refers to the mechanism whereby actors associated with an incumbent technology greatly increase their innovative efforts when the established technology is challenged by a new technology. The term sailing ship effect was coined by Ward (1967), who referred to improvements in sailing ships when steamships challenged them in the 1860s and 1870s.

European farmers and led to the agricultural crisis of the 1890s. Steamships also contributed to the mass immigration to America in the late 19th and early 20th century. The transition to steamships thus contributed to many wider social and economic transformations (see Geels, 2002b).

The description of the four phases shows that the MLP is able to encompass insights from several disciplines. In Figure 6 I have schematically positioned the different disciplinary building blocks from Section 2 in the MLP, thus highlighting its integrative strength.

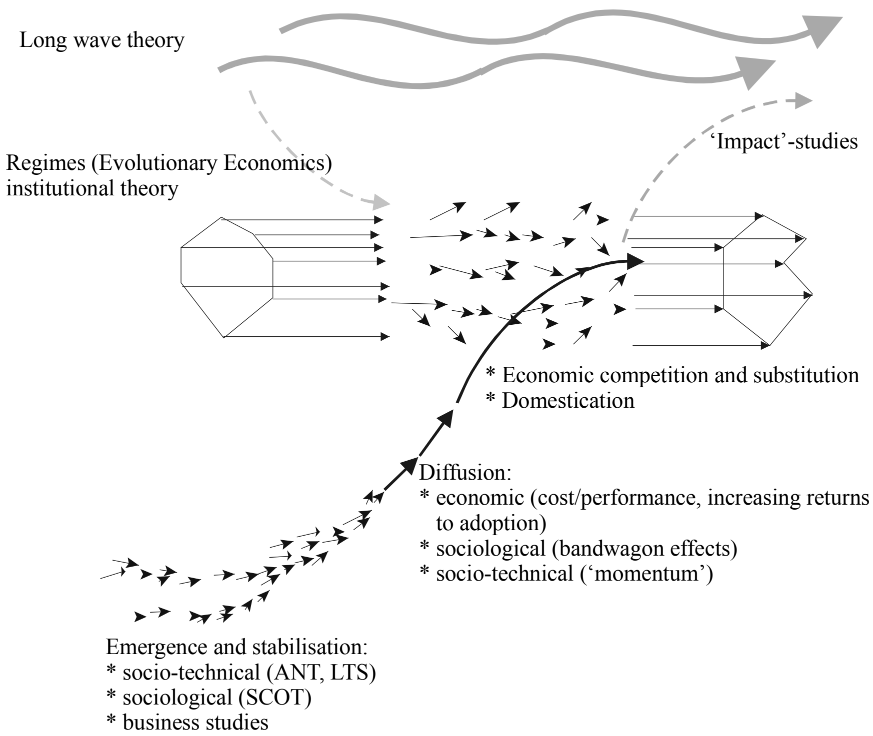

Figure 6. Positioning of different disciplines in the Multi-Level Perspective (Geels, 2004)

Empirical applications

The MLP has been empirically illustrated with historical case studies. Geels (2002b) studies the transition from propeller-piston engine aircraft to turbojets (1926-1975), the transition from sailing ships to steamships (1780-1914), and the transition in urban land transportation from horse-and-carriage to automobiles (1860-1930). Belz (2004) uses the MLP to study the ongoing transition in Switzerland (1970-2000) from industrialised agriculture to organic farming and integrated production. Van Driel and Schot (2001) use the perspective to study a transition in the transhipment of grain in the port of Rotterdam (1880-1910), where elevators replaced manual (un)loading of ships. Raven (2004) uses the perspective to study the niches of manure digestion and co-combustion in the electricity regime.

4. POLICY SUGGESTIONS

System innovations are complex, uncertain and involve multiple social groups. Hence policy makers puzzle over how they can influence system innovations. The state is not an all-powerful and all-knowing actor in this matter. Public authorities are only one social group amongst others. Like other groups, they have limited power, a limited cognitive perspective and limited resources to influence system dynamics. This recognition is represented in a shift in policy studies from a focus on government to governance (*e.g*. Kooiman, 1993; Kohler-Koch and Eising, 2000). Governance means that there is directionality and coordination at the systems level, but that it does not stem from one social group (*e.g*. policy makers). Directionality and coordination thus have an emergent character, arising from the interaction among groups. Public authorities may try to influence this, but cannot steer it at will. This means one has to be modest about the possibility for policy makers to steer system innovations. This is in line with the MLP, which highlights the importance of 'windows of opportunity' and the alignment of multiple developments. When existing socio-technical regimes are stable, policy makers cannot simply 'force' major changes, but they can stimulate variety at the niche level and try to modulate ongoing processes in the regime, aiming to make connections between the two levels. Different policy instruments can be used for these ends. The MLP does not so much propose *new* instruments, but suggests an overall framework for a better alignment of existing instruments. Let us first look at different instruments and then return to the MLP.

There is a wide range of policy instruments which stem from three different governance paradigms: *(i)* the traditional top-down model, with a central role for (national) government and hierarchical relations; *(ii)* a bottom-up market model, with a large degree of autonomy for local actors; *(iii)* a policy networks model, where actors are interdependent and have diverging values and beliefs. These three governance paradigms have different disciplinary backgrounds, focus on different aspects, encompass different notions about the relationship between the government and other actors, and propose different policy instruments (see Table 1). Formal rules and regulations are instruments typical to the command-and-control paradigm, while subsidies, taxes and (financial) incentives are common in the market model. Within the policy network paradigm the conspicuous leverages and instruments are learning processes, creation of shared visions, experiments and interactive policymaking.

Table 1. Different policy paradigms (based on De Bruijn et al., 1993: 22)

	Classic steering paradigm (top-down, command-and-control)	**Market model (bottom-up)**	**Policy networks (processes and networks)**
Level of analysis	Relationship between principal and agent	Relationship between principal and local actors	Network of actors
Perspective	Centralised, hierarchical organisation	Local actors	Interactions between actors
Characterisation of relationships	Hierarchical	Autonomous	Mutually dependent
Characterisation of interaction processes	Neutral implementation of formulated goals	Self organisation on the basis of autonomous decisions	Interaction processes in which information and resources are exchanged
Foundational scientific disciplines	Classic political science	Neo-classical economy	Sociology, innovation studies, neo-institutional political science
Governance instruments	Formal rules, regulations and laws	Financial incentives (subsidies, taxes)	Learning processes, network management through seminars and strategic conferences, experiments, vision building at scenario workshops, public debates

It is too simple to say that one paradigm is right and the others wrong. They emphasise different aspects of a (complex) reality. I argue that instruments from all three governance paradigms are needed to stimulate system innovations rather than making a choice for one particular instrument. I will use the MLP to formulate a general policy strategy to stimulate system innovations, and situate instruments in different phases and at different levels.

According to the MLP, a general transition policy strategy must have two characteristics. On the one hand, pressure on the existing regime should be increased. This can be done with financial instruments (*e.g.* carbon tax) and regulations (tradable emission rights, emission norms). On the other hand, radical innovations should be stimulated to emerge in niches. This requires more specific governance policies, *e.g.* subsidies for experimentation, network management to enrol the right actors in the niche, and the development of guiding visions and future expectations (*e.g.* Rotmans *et al.*, 2001; Hoogma *et al.*, 2002). This does not mean that governments 'pick the winners,' but that variety in innovation needs to be stimulated and guided.

This general strategy can be further refined. Different kinds of policies are needed in different phases and at different levels. In the first two phases, we need policies on the niche level to stimulate experimentation, learning, network building and vision building. Instruments from the network governance paradigm are relevant here. At the same time, regulative and financial instruments are needed to put pressure on the regime. There is no need to make this pressure very strong, unless the novelties have been improved sufficiently in niches (stabilised design, substantial improvements in price and performance). In the third and fourth phases, the system innovation gains momentum and goals become clearer. Policies are needed to push the new technology (*e.g.* regulations, adoption subsidies). Wide diffusion also requires adjustments in the socio-technical regime (*e.g.* new infrastructures, maintenance networks, regulations). Policies are needed for adjustment and structural change. At the same time, impacts of the new technology need to be monitored, and as more is learned about them, adjustment of policies is needed. Figure 7 schematically represents how instruments from different policy paradigms can be situated in different phases and levels.

The positioning of different policy instruments is ideal-typical and based on theory. The importance and precise mix of instruments may vary between domains and over time. Furthermore, countries may have different policy cultures, preferring different instruments, *e.g.* the US may prefer market-instruments, while the Netherlands chooses policy network instruments. However, scientific understanding has not progressed far enough to make robust conclusions about the 'best' mix of instruments in different domains, times and countries.

But we can take one further step. Because effective policies depend on windows of opportunity, it is helpful to identify some of those windows. Small interventions at the right moment can have large impacts later on. Here are some suggestions:

– Identify not only appropriate *initial* niches to experiment with new technologies, but also think in terms of *trajectories of niche-accumulation*. What could be the subsequent niches and application domains for the innovation?

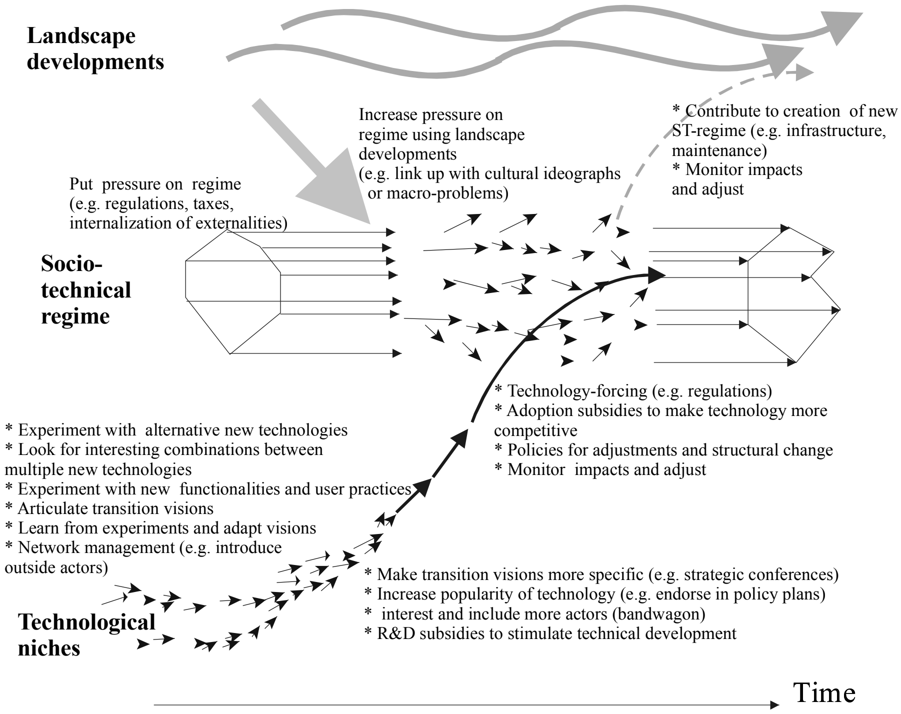

Figure 7. Different transition policies in different phases (Geels, 2002b: 363)

- Rather than focusing on single technologies as solutions, look for interesting combinations of *multiple* technologies. The transition to steamships occurred because three technical trajectories linked and reinforced each other: screw propulsion (instead of paddle wheels), iron hulls (instead of wood), and more efficient steam engines (compound engines) — which, in turn, depended on steel rather than iron;
- Search for possibilities of technical add-on and hybridisation as stepping-stones. Steam engines and paddle wheels were first used as auxiliary devices on sailing ships. Gas turbines were first used as auxiliary supercharging devices in piston-engine aircraft;
- Take advantage of market dynamics. Novelties may break out of niches by piggy-backing on the growth of particular market niches. If there is a market trend towards a second car in households, policy makers can oppose this dynamic to fight congestion. But they may also acknowledge the trend and try to stimulate the use of Battery-Electric Vehicles (BEV) in this market. This secondary market may then provide a stepping-stone for the diffusion of radical technology;
- Use new technologies to experiment with new functionalities and new user patterns. If innovations can be used in *new* markets, they need not

fight with incumbent technologies head-on. This means that established user patterns should not be taken for granted, but should be tested and questioned;
- Try to bring outsiders into the game. Incumbent actors may have too many vested interests to nurture a radical innovation. An outsider may speed up dynamics, and introduce new ways of doing and thinking.

5. TOPICS FOR FURTHER RESEARCH

The MLP provides an interesting overall perspective to understand system innovations. It has some strengths and weaknesses with regard to three scientific criteria: scope, empirical validity and simplicity (Ockham's razor). Strength of the MLP is its scope and generalizability. The perspective is broadly encompassing and able to combine contributions from sociological, economic and socio-technical theories. Another strength is that the perspective can accommodate complex empirical reality, although I have not been able to give detailed evidence of this point here (but see the references). A weakness is the use of metaphors and rather imprecise concepts (*e.g.* landscape, opening up, windows of opportunity). A problem for academics who like to make computer models is the low degree of simplicity. The perspective is fairly complex, requiring attention to dynamics at multiple levels.

There are also several gaps that need to be filled in with further research. One topic for further research is the elaboration of the multi-level perspective in terms of transition routes, patterns and mechanisms. A second topic is to look at the interaction among multiple niches. The MLP currently suggests that system innovation is about the breakthrough of one niche but there may be multiple niches accomplishing this. These niches can compete with each other, but they may also reinforce each other or co-exist with little interaction. This is an open and interesting topic.

A third topic is that closer cooperation should be sought with other disciplines, *e.g.* innovation studies and business studies. The sectoral systems of innovation approach, for instance, may have interesting insights to offer (Breschi and Malerba, 1997; Malerba, 2002), and from business studies we may learn more about the role of firms in different stages of system innovations, *e.g.* the relationship between incumbent firms and outsiders.

A fourth suggestion is to widen the empirical basis. More case studies should be done of system innovations, chosen from different domains so that the importance of different variables can be analysed (*e.g.* with or without infrastructure; private versus public sector; sectors with few large firms versus many small firms; internal problems versus negative externalities). When historical case studies are done, attention should be paid to the issue of the applicability of received insights to present-day contexts.

A fifth topic is the definition of boundaries. This is relevant for all research dealing with systems. More work should be done on this issue, because it is important to have the unit of analysis clear. On the other hand, perhaps we should not over-emphasise this issue. Particularly with regard to social networks, it is simply not possible to define boundaries once and for all. Social groups and the networks among them are the outcome of historical differentiation processes. The network of social groups, and associated socio-technical systems, develops over time. Relationships between social groups shift and new groups emerge. In the electricity sector, for instance, liberalisation has given electricity distribution companies a more prominent role, and electricity traders in spot markets have emerged as an entirely new group. Another point is that the specific network of social groups shows great differences between sectors. The social networks in transport systems look and function differently than in electricity systems. Questions about boundary definition always occur in systems and networks, but this is more an empirical issue than a theoretical one.

A sixth topic is the relationship between different policy paradigms. More should be done to determine how different instruments should be used in different phases. Historical case studies may act as an interesting mirror, but more attention also needs to be paid to differences between domains, times and countries. More international comparative work is required as system transformations become an increasing concern globally.

ACKNOWLEDGEMENTS

I want to thank Ruud Smits, Xander Olsthoorn, Anna Wieczorek and two anonymous referees for their useful comments on earlier versions of this chapter.

REFERENCES

Arrow, K. (1962), The economic implications of learning by doing, *Review of Economic Studies*, 29, 155-173

Belz, F.M., (2004), A transition towards sustainability in the Swiss agri-food chain (1970-2000), in Elzen *et al.* (eds.), *System Innovation and the Transition to Sustainability: Theory, Evidence and Policy*, Cheltenham: Edward Elgar (forthcoming)

Berkhout, F. (2002), Technological regimes, path dependency and the environment, *Global Environmental Change*, 12, 1-4

Bijker, W.E. (1995), *Of Bicycles, Bakelites and Bulbs: Towards a Theory of Sociotechnical Change*, Cambridge and London: The MIT Press

Braudel, F. (1958), Histoire et sciences sociales: La longue durée, *Annales*, 13, 725-753

Breschi, S. and F. Malerba (1997), Sectoral Innovation Systems: Technological Regimes, Schumpeterian Dynamics, and Spatial Boundaries, in C. Edquist (ed.), *Systems of Innovation: Technologies, Institutions and Organizations*, London and Washington: Pinter, 130-156

Brown, N. and M. Michael (2003), The sociology of expectations: Retrospecting prospects and prospecting retrospects, *Technology Analysis & Strategic Management*, 15, 3-18

Burns, T.R. and H. Flam (1987), *The Shaping of Social Organization: Social rule system theory with applications*, London: Sage Publications

Callon, M. (1991), Techno-economic networks and irreversibility, in J. Law (ed.), *A sociology of Monsters*, *Essays on Power, Technology and Domination*, London: Routledge, 132-161

Christensen, C. (1997), *The innovator's dilemma: When new technologies cause great firms to fail*, Boston: Harvard Business School Press

De Bruijn, J.A., W.J.M. Kickert and J.F.M. Koppenjan (1993), Hoofdstuk 1: Inleiding: Beleidsnetwerken en overheidssturing, in J.F.M. Koppenjan, J.A. De Bruijn and W.J.M. Kickert (eds.), *Netwerkmanagement in het openbaar bestuur*, Den Haag, Vuga, 11-30

Dosi, G. (1982), Technological Paradigms and Technological Trajectories: A Suggested Interpretation of the Determinants and Directions of Technical Change, *Research Policy,* 6, 147-162

Freeman, C. and C. Perez (1988), Structural crisis of adjustment, business cycles and investment behaviour, in G. Dosi, C. Freeman, R. Nelson, G. Silverberg and L. Soete (eds.), *Technical Change and Economic Theory*, London: Pinter, 38-66

Garud, R. and P. Karnøe (2001), Path creation as a process of mindful deviation, in R. Garud, and P. Karnøe (eds.), *Path Dependence and Creation*, Mahwah: Lawrence Earlbaum Associates, 1-38

Geels, F.W. (2002a), Technological transitions as evolutionary reconfiguration processes: A multi-level perspective and a case-study, *Research Policy*, 31 (8/9), 1257-1274

Geels, F.W. (2002b), *Understanding the Dynamics of Technological Transitions, A co-evolutionary and socio-technical analysis*, PhD thesis, Enschede: Twente University Press

Geels, F.W. (2004), Understanding Technological Transitions: A critical literature review and a pragmatic conceptual synthesis, in B. Elzen, F.W. Geels and K. Green (eds.), *System Innovation and the Transition to Sustainability: Theory, Evidence and Policy*, Cheltenham: Edward Elgar (forthcoming)

Hodgson, G.M. (1998), The Approach of Institutional Economics, *Journal of Economic Literature*, 36, 166-192

Hoogma, R., R. Kemp, J. Schot and B. Truffer (2002), *Experimenting for Sustainable Transport: The approach of Strategic Niche Management*, London and New York: Spon Press

Hughes, T.P. (1987), The Evolution of Large Technological Systems, in W.E. Bijker, T.P. Hughes and T. Pinch (eds.), *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology*, Cambridge: The MIT Press, 51-82

Hughes, T.P. (1994), Technological Momentum, in M.R. Smith and L. Marx (eds.), *Does Technology Drive History? The Dilemma of Technological Determinism*, Cambridge: The MIT Press, 101-113

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

Kemp, R. (1994), Technology and the Transition to Environmental Sustainability. The Problem of Technological Regime Shifts, *Futures* 26, 1023-1046

Kemp, R, J. Schot and R. Hoogma (1998), Regime shifts to sustainability through processes of niche formation: the approach of strategic niche management, *Technology analysis and strategic management*, 10, 175-196

Kemp, R., A. Rip and J. Schot (2001), Constructing Transition Paths Through the Management of Niches, in R. Garud and P. Karnoe (eds.), *Path Dependence and Creation*, Mahwah: Lawrence Erlbaum Associates Publishers, 269-299

Kohler-Koch, B. and R. Eising (eds.) (2000), *The Transformation of Governance in the European Union*, London and New York: Routledge

Kooiman, J. (ed.) (1993), *Modern Governance: New government-society interactions*, London: Sage

Latour, B. (1987), *Science in Action*, Cambridge: Harvard University Press

Latour, B. (1991), Society is technology made durable**,** in J. Law (ed.), *A sociology of Monsters*, *Essays on Power, Technology and Domination*, London: Routledge, 103-131

Leonard-Barton, D. (1995), *Wellsprings of knowledge: Building and sustaining the sources of innovation*, Boston: Harvard Business School Press

Lie, M. and K.H. Sørensen (eds.) (1996), *Making technology our own: Domesticating technology into everyday life*, Oslo: Scandinavian University Press

Lynn, G.S., J.G. Morone and A.S. Paulson (1996), Marketing and discontinuous innovation: The probe and learn process, *California management review*, 38, 8-37

Malerba, F. (2002), Sectoral systems of innovation, *Research Policy*, 31, 247-264

Mayntz, R. and T.P. Hughes (eds.) (1988), *The development of large technical systems*, Frankfurt: Campus Verlag; and Boulner: Westview Press

Molina, A. (1995), Sociotechnical constituencies as processes of alignment: The rise of a large-scale European information technology initiative, *Technology in Society*, 17, 385-412

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

American NRC (1999), *Our Common Journey. A transition toward sustainability*, Washington: National Academy Press

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

North, D.C. (1990), *Institutions, Institutional Change and Economic Performance*, Cambridge: Cambridge University Press

Parsons, T. (1937), *The Structure of Social Action*, New York: McGraw-Hill

Pinch, T.J. and W.E. Bijker (1987), The social construction of facts and artifacts: Or how the sociology of science and the sociology of technology might benefit each other, in W.E. Bijker, T.P. Hughes and T.J. Pinch (eds.), *The social construction of technological systems: new directions in the sociology and history of technology,* Cambridge: MIT Press, 17-50

Raskin, P. T. Banuri, G. Gallopin, P. Butman, A. Hammond, R. Kates and R. Swart (2002), *Great Transition. The promise and lure of the times ahead*, Boston: Stockholm Environment Institute

Raven, R.P.J.M. (2004), Implementation of manure digestion and co-combustion in the Dutch electricity regime: A multi-level analysis of market implementation in the Netherlands, *Energy Policy*, 32, 29-39

Rip, A. and R. Kemp (1998), Technological Change, in S. Rayner and E.L. Malone (eds.), *Human Choice and Climate Change, Volume 2*, Columbus: Battelle Press, 327-399

Rotmans, J., R. Kemp and M. van Asselt (2001), More Evolution than Revolution: Transition Management in Public Policy, *Foresight*, 3, 15-31

Scott, W.R., (1995), *Institutions and* organisations, London and New Delhi: Sage publications

Schot, J.W. (1998), The Usefulness of Evolutionary Models for Explaining Innovation. The Case of the Netherlands in the Nineteenth Century, *History of Technology*, 14, 173-200

Schot, J., R. Hoogma and B. Elzen (1994), Strategies for Shifting Technological Systems. The case of the automobile system, *Futures*, 26, 1060-1076

Staudenmaier, J.M. (1989), The Politics of Successful Technologies, in S.H. Cutliffe and R.C. Post (eds.), *In Context: History and the History of Technology: Essays in Honor of Melvin Kranzberg*, Bethlehem: Lehigh University Press, 150-171

Unruh, G.C. (2000), Understanding carbon lock-in, *Energy Policy*, 28, 817-830

Van Driel, H. and J. Schot (2001), Regime-transformatie in de Rotterdamse graanoverslag, NEHA-jaarboek voor economische, bedrijfs- en techniekgeschiedenis, *NEHA (Nederlandse Economisch-Historisch Archief)*, 64, 286-318

Van Lente, H. (1993), *Promising technology: The dynamics of expectations in technological development*, PhD thesis, Twente University, Delft: Eburon

Vellinga, P. and Herb, N. (eds.) (1999), *Industrial Transformation Science Plan*, IHDP Report No 12, Bonn: International Human Dimensions Programme

VROM (2001) *Een wereld en een wil, werken aan duurzaamheid, Nationaal Milieubeleidsplan 4* (Dutch Environmental Policy Plan 4, established by nine Dutch departments under the coordination of the Department of Housing, Planning and Environment), The Hague: Ministry of VROM

Weterings, R., J. Kuijper, E. Smeets, G.J. Annokkée and B. Minne (1997), *81 mogelijkheden voor duurzame ontwikkeling*, The Hague: Ministry of VROM