2 The Dynamics of Innovation: A Multilevel Co-Evolutionory Perspective

Ellen H.M. Moors, Arie Rip and Johannes S.C. Wiskerke

Introduction

There is a long tradition of institutional design, in practice and as a challenge for social scientists (e.g. Ostrom 1990, 1992). Many studies and analyses of the subject have been made, often drawing upon neo-institutional economical theory (for an authoritative review see Weimer 1995). However these studies have often insufficiently taken into account the role of material aspects in the socio-technical design activities, which are increasingly important in today's world and in the case of agriculture, have always been important. While the importance of the socio-technical is occasionally recognised (for example in energy policy, cf. Arentsen and Künneke 1996), the technical and material often tend to be accepted as given and thus not subject to examination. This point has been made before in science and technology studies, most forcibly by Latour (e.g. 1992), but little attention has been paid to the possibility of developing systematic technico-institutional design. Occasionally the possibilities of this have been explored, but from the context of specific domains, for example computer-supported collaborative work (see e.g. DeSanctis and Poole 1994; Rogers 1994).

Further related entrées to the subject have been provided by technology assessment (TA), in particular constructive technology assessment (CTA) (Rip *et al.* 1995). Schot and Rip (1997) emphasise the importance of feedback within technological developments (which in turn is based upon an understanding of their socio-technical dynamics) which occurs in interaction with assessment of possible impacts, thereby generating an iterative learning process. Out of this traditional concern of TA with identifying potential impacts, there is now a growing interest in influencing (socio-)technical development. A number of ways of approaching this have been identified.

While such studies have made important contributions to understanding the dynamics of innovation, most of these studies and 'natural' technico-institutional design activities have not explicitly or systematically located themselves within the context of existing and evolving technical regimes.

In some instances the need for a regime change is identified (for example in the motorcar regime, or with respect to problems of global climate change) but the means for examining how such a change might be achieved is rarely explored. Available historical and retrospective sociological studies of the emergence, stabilisation and transformation of regimes (for interesting examples see: Marvin 1988; Stoelhorst 1997; Van den Ende 1994; Van de Poel 1998) provide some basis for understanding positive and negative design heuristics ('do's' and 'don'ts') that contribute towards this. Kemp *et al.* (1997) have further contributed to this, by conceptualising transition paths from an existing regime to a possible (and hopefully better) one. They identified strategic niche management as a particularly effective approach in achieving this. Drawing upon the typical approach of selecting and studying interesting 'natural' cases, it goes further and sets up 'experimental' cases (most often, by intentionally modifying 'natural' cases) and evaluating them (Schot *et al.* 1996; Kemp *et al.* 1998; Weber *et al.* 1999; Hoogma *et al.* 2002; see also Rip 1995).

In order to develop a technico-institutional design method, which touches on both the material and the socio-institutional components of novelties (in this case agricultural developments) and, especially, on the complex interrelations between the two, we argue that a dynamic, multi-level, co-evolutionary, perspective is required. The basic idea is that the diverse innovation processes and technology choices at the local level accumulate as technological developments at the societal level. In developing such a perspective we take the multi-level, multi-actor and multi-aspect dynamics of socio-technical change into account, with the focus on the interaction between technology and society, conceptualised as the process of co-evolution or co-production in which technology and social context interact and change. Accordingly, a multi-level analysis simultaneously addresses material/technical realities, patterns of socio-technical interaction and the impacts of collective action (collective experiments) that aim to secure a shift in technico-institutional design towards new forms of agricultural development.

In order to set up new structures and ways of achieving technico-institutional design in agricultural development, we need to understand the co-evolutionary dynamics of interaction between the natural, the technical and the institutional. This is of particular relevance when seeking changes in the direction of the existing regime (as is currently with attempts to turn the present industrial agricultural regime into one that is sustainable). We also need to understand the relationship between 'novelty creation' (generated within agriculture), its nurturing or repression (within the institutional sphere) and regime evolution or transition (widespread acceptance and adoption across society). This again merits particular attention when the novelties hold promise, but appear frail or inconsequential in comparison to the dominant regime – having the characteristics of what Mokyr (1990) and Stoelhorst (1997) call 'hopeful monstrosities.'

A better understanding of the co-evolutionary innovation dynamics in agricultural practices can be reached by taking a multi-level perspective on innovation processes, studying the overall transition process in agricultural regimes. The next section of this chapter describes on transition processes. Next, we focus on the underlying dynamics of socio-technical innovation processes, and in particular upon the general patterns and mechanisms involved in transition processes. The fourth section of this chapter provides an introduction to the concept of strategic niche management. The chapter ends with some concluding remarks on the way in which transition processes might be most effectively managed.

A multi-level perspective on innovation: studying the overall transition process

Socio-technical developments in various economic and societal sectors, such as households, transport, energy, industrial production and agriculture, are required in order for us to meet the challenge of sustainable development. Although these sectors have the potential to become sustainable, through socially and environmentally benign technological developments, they are presently important sources of environmental degradation and are far from sustainable. The agricultural sector, for example, pollutes its environment by emitting high amounts of ammonia, nitrate, and pesticides, reduces biodiversity and uses a lot of energy for crop growth and transportation. The necessity to break the current trends in agricultural practices requires fundamental renewals and breakthrough changes, changes that will take decades. So it is important that the process of change should be initiated as soon as possible (Jansen 1993; Moors and Mulder 2002). Therefore, a transition is necessary, from a scale-intensive, specialised, high production-oriented agriculture system to a new, more sustainable agricultural system, whose features would include minimal environmental degradation, minimal use of external inputs, multifunctional soil use, and embeddedness in local ecological conditions and cultural practices. Such a regime-shift in agriculture is an essential component of any programme for sustainable development.

Transition processes

Transitions are regarded as large transformation processes in which large parts of society change, in a fundamental way, over a generation or more. A transition then, can be defined as a gradual, continuous process of change, in which the structural character of a society (or a complex sub-system of society) transforms (Rotmans *et al.* 2000). Transitions are not uniform, and nor is the transition process deterministic: there are large differences in the scale of change and the period over which it occurs. Furthermore, although various actors carry a certain picture of the ultimate goal of the transition process in their minds, the form and content of the transition process are not predetermined. Transitions involve a range of possible development paths, whose direction, scale and speed can be influenced, but never entirely controlled, by individual actors (e.g. governmental policies). Transitions involve the emergence and development of new technologies as well as their diffusion into user domains and societal embedding. During the process of transition adaptation to, and learning from, new situations can take place, thereby influencing the overall transition process.

A transition is the result of developments in different domains. It can be described as a set of connected changes, which reinforce each other, even though they take place in several areas, such as technology, institutions, culture and belief systems. A transition can be regarded as a spiral that reinforces itself; there is multiple causality and co-evolution, caused by independent developments. Transitions are characterised by influencing and reinforcing economic, ecological, social cultural and institutional practices. Because transitions are multi-dimensional with different dynamic layers, their occurrence requires several developments to come together in several domains in the same timeframe. At the conceptual level we can distinguish four transition phases (Rotmans *et al.* 2001):

1 A *pre-development phase* of dynamic equilibrium where the status quo does not visibly change, but where different options and ideas for change are created and exchanged.
2 A *take-off phase* where the process of change gets under way because the state of the system begins to shift, due to the fact that actors are mobilised around promising perspectives.
3 A *breakthrough or acceleration phase* where visible structural changes take place through an accumulation of socio-cultural, economic, ecological and institutional changes that react to each other. During the acceleration phase, there are collective learning processes, diffusion and embedding processes.
4 A *stabilisation phase* where the speed of social change decreases and a new dynamic equilibrium is reached.

Different social processes come into play during the various phases. It is important to emphasise that fundamental changes do not necessarily occur in all the domains at the same time Transitions also generally have periods of slow and of rapid development. A transition is a gradual, continuous process typically spanning at least one generation (approximately 25 years). Because the established equilibrium of the dominant regime involves stability and inertia, a transition also implies a fundamental change of assumptions and the introduction of new practices and rules (Rotmans *et al.* 2001:17). Transitions can however be initiated or accelerated by unexpected or one-off events: for example a war, the oil crisis, or the BSE, swine fever, Foot and Mouth Disease and Avian Influenza crises in agriculture.

Co-evolutionary perspectives on innovation

Linear models of technological change and innovations assume innovation to be more or less independent of social forces and to be a predominantly technologically driven process. It assumes these changes proceed in a unidirectional and predetermined manner, starting with basic research and ending with the market adoption and dissemination. This then corresponds with the linear, three-stage, science-driven sequence of innovation from invention through innovation towards implementation. While this linear model of the innovation process provides an initial analytical framework that is applicable to some circumstances, there are distinct limitations to this approach (Moors 2000). First, innovations are not linear at all. While there are some logical priorities in the sequence of stages, there are numerous variations on the presumed sequence. Very often, an inventive research effort is a problem-solving response to some perceived need in the market. Accordingly, feedback and 'feedforward' cycles of information exchange are an important part of the innovation process. In addition, there are many shocks and unpredictable setbacks and surprises that can undermine the facile notion of a linear model of innovation, which show that innovation is, in fact, a highly iterative process. In other words, the linear model does not explain the dynamics of innovation, either in terms of the forces that drive and inspire innovation or those that constrain and frustrate it.

An additional shortcoming of linear models closely related to the first limitation, is the overly simplistic way in which the roles of groups of actors are allocated to specific and defined stages. Thus, the linear model suggest that it is only researchers who control the shape and content of research, that assembling and manufacturing belong purely to the domain of technicians, and that consumers and industry are the almost passive recipients of these processes. However, social studies of technology clearly demonstrate that the demands and concerns of end-users and interest groups are incorporated in the research agendas of firms (Rip and van de Velde 1997).

Taken together, these limitations provide sufficient grounds to argue that there is a clear need to reassess the traditional linear innovation model so that it includes iterative, interactive and complex dynamic process, that involve many factors and actors and which gives a central role to feedback and feedforward loops. The innovation process can then be regarded as an innovation journey with setbacks and changes in direction: as a 'trail of trials', continuously being influenced by the contexts that it encounters along its path (van de Ven *et al.* 1989; Rip and Schot 1999).

The existence of long term trends in technological change is widely recognised. Examples include the use of information technology in manufacturing and offices, the electrification of products and processes and, on the consumer side, the use of automobiles for transport. Economists, sociologists and historians have studied these regularities in technological change and have proposed various ways of explaining the ordering and structuring of technological change. Two concepts have been highly influential in the social studies of technology literature: the concept of technological regime introduced by Nelson and Winter (1977), and Dosi's concept of technological paradigm (Dosi 1982).

Nelson and Winter (1977) noted that the problem-solving activities of engineers were not fine-tuned to changes in cost and demand conditions, but were relatively stable, focused on particular problems and informed by certain notions (derived from an engineering background) of how to deal with these problems. They developed a theory of economic change, which included an evolutionary theory of technological change, This approach drew upon the biological metaphor of evolution to describe the innovation process. Thus, technological development was described as having two distinct elements: variation and selection.

Dosi (1982) introduced the idea of a technological paradigm, analogous to Kuhn's (1962) concept of a scientific paradigm. A technological paradigm consists of an exemplar (an artefact that is to be developed and improved) and a set of (search) heuristics, or engineering approaches, based on technicians' ideas and beliefs of where to go, what problems to solve, and what knowledge to draw upon.

The idea of a core technological framework that guides industrial research activities has gained wide acceptance in modern innovation theory. An advantage of this approach is its connection to existing engineering ideas and approaches, which traditional economic theories fail to achieve. But its ability to explain socio-technical change is limited, as it focuses excessively upon the cognitive aspects of problem-solving activities and places too little emphasis on the interplay between cognitive, economic and other social factors that force technological problem-solving in certain directions.

This interplay can be perceived as a co-evolutionary process of variation and selection, in which external selection pressures are anticipated by the innovator and incorporated into R&D programmes. The external selection environment is, in turn, shaped by the policies of the supplier and other actors who strive to promote (and control) a particular technology (for a more detailed discussion of the co-evolution of technology and society see Rip and Kemp 1998).

Engineering practices are embedded in larger technological regimes which not only consist of a set of opportunities but also provide a set of constraints, in the form of established practices, supplier-user relationships and consumption patterns (Hoogma *et al.* 2002:18-19). Accordingly, accounts of how technological regimes evolve need to encompass both the paradigmatic framework of engineers as well as broader social and economic influences. Rip and Kemp (1998) define a technological regime as

> *'the whole complex of scientific knowledge, engineering practices, production process technologies, product characteristics, skills and procedures, established user needs, regulatory requirements, institutions and infrastructures.'*

A technological regime incorporates a cognitive and normative framework and a set of (functional) relationships between the technological components and the actors along the product chain. This framework forms the basis for individual and collective action and provides the context for technological and economic practices within a product chain, which predefine – both the problem-solving activities that engineers are likely to undertake and the strategic choices of companies.

The term regime is used in preference to paradigm or system because it refers to a set of rules. These rules not only take the form of a set of commands and requirements, but also include the roles of actors and established practices that are not easily displaced. They provide the search heuristics of engineers, product standards, manufacturing practices, standards of use, and the division of roles. These rules guide (but do not fix) the type of research activities that companies within a technological system are likely to undertake, the directions from which solutions will be chosen and the strategies of actors (manufacturers, suppliers, governments and users). Technological regimes are therefore a broader, socially embedded version, of technological paradigms. The nature of socio-technical change is in large part proscribed by the embeddedness of existing technologies in broader systems, in production practices and routines, consumption patterns, engineering and management belief systems and cultural values. This embeddedness creates economic, technological, cognitive and social opportunities for some new technologies and barriers for others (Hoogma *et al.* 2002:20). The notion of technological regime helps explain why most change is incremental aimed at optimising the existing regime rather than radically transforming it. It also helps to explain why so many promising new technologies remain on the shelf. This is especially true of systemic technologies that have long development times and that require changes in the selection environment (for example, in regulation, consumer preferences, infrastructure, and price structure). Radically new technologies require changes on both the supply and demand sides, which usually take time and meet a lot of resistance, even within the organisation in which they are produced. Firms with a vested interest in old technologies will be more inclined to reformulate their existing products rather than to do something radically new, that may involve great risk. Both supply-side and demand-side changes are needed to introduce radically new technologies successfully. Such changes require new ideas, production and user practices, the development of complementary assets and institutional change at the level of organisations and markets (Rip and Kemp 1998).

Dynamics of technological transitions/regime-shifts

What is involved when changes in technological regimes occur? Obviously, each technological transition or regime shift is unique in its own way, but some general features can be observed. Studies of technological transitions have identified the following elements as key aspects of technological regime shifts (Kemp 1994; Hoogma *et al.* 2002).

- *Long periods of time.* It often takes one generation (20-30 years) for a new technological regime to replace an old one.
- Deep *interrelations between technological progress and the social/managerial context* in which they are put to use. Radically new technologies give rise to specific managerial challenges and new user-supplier relationships; they require and generate changes in the social fabric and often meet resistance from vested interests; they give rise to public debates over the efficacy and desirability of the new technology.
- New technologies tend to involve *'systems' of related techniques*; the economics of the processes thus depend on the costs of particular inputs and availability of complementary technologies. Technical changes in such related areas may be of central importance to the viability of any new regime.
- *Perceptions and expectations* of a new technology are of considerable importance, including engineering ideas, management beliefs and expectations about the market potential, and, on the user side, perceptions of the technology. These beliefs and views about the new technology are highly subjective, and will differ across (professional and social) communities. They are in constant flux, and their evolution may provide a barrier or a catalyst to the development and acceptance of a particular technology.
- The importance of *specialised application in the early phase of technology development*. In the early phase of the development of a radically new technology there is usually little or no immediate economic advantage to be gained. At the same time incremental improvements to the existing technologies make it more difficult for the new one to compete and acquire a foothold in the market.

Accordingly, technological regime shifts, entail a number of structural changes at different levels. The emergence of a new technological regime implies the simultaneous evolution of these changes. This is a co-evolutionary process: technological options, user preferences and the necessary institutional changes are not given *ex-ante*, but need to be created and shaped. User demands are articulated and expressed in the process itself, in interaction with the available technological options. Producers learn new ways of viewing their own technology.

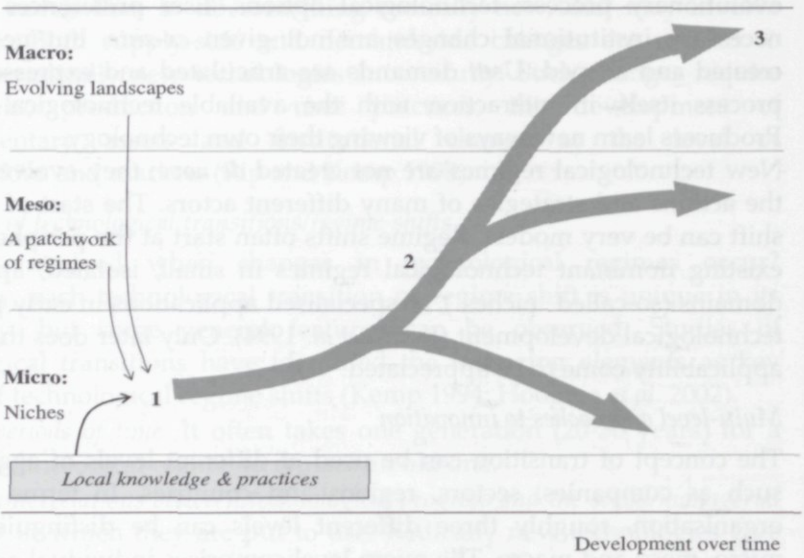
New technological regimes are not created *de novo*; they evolve through the actions and strategies of many different actors. The start of a regime shift can be very modest. Regime shifts often start at the periphery of the existing dominant technological regimes in small, isolated, application domains (so-called 'niches'), as specialised applications in early phases of technological development (Kemp *et al.* 1994). Only later does their wider applicability come to be appreciated.

Multi-level approaches to innovation

The concept of transition can be used at different levels of aggregation, such as companies, sectors, regions and countries. In terms of social organisation, roughly three different levels can be distinguished: the micro, meso and macro. The micro level comprises individual actors (e.g. in terms of agriculture, farmers and environmental groups). The meso level comprises networks, communities and organisations (e.g. agricultural production systems). The macro level comprises conglomerates of institutions and organisations (e.g. a nation). This division of micro, meso and macro levels corresponds closely with the classifications used by Rip and Kemp (1998) to describe changes in socio-technical systems, namely the division into niches, regimes, and socio-technical landscapes.

The socio-technical landscape encompasses material and immaterial elements at the macro level: material infrastructure, political culture and coalitions, social values, worldviews and paradigms, the macro economy, demography and the natural environment. The meso level of (socio-technical) regimes describes dominant practices, rules and shared assumptions. At the meso level are the interests, rules and beliefs that guide private actions and public policy – for the most part geared towards optimising rather than transforming systems. The niche level (micro level) describes individual actors and technologies and local practices. At this level, variations to, and deviations from, the status quo can occur, such as new techniques, alternative technologies and social practices. Figure 1 illustrates the multi-layered structure of socio-technical change.

Figure 1 General pattern of socio-technical change: 1 = Novelty creation; 2 = Novelty evolves, is taken up, may modify regime; 3 = Landscape is transformed (After Rip and Kemp 1998)



Often in the early period of socio-technical transition, the regime serves to inhibit change. Typically it will seek to improve existing technologies and use strategic actions to fight off new developments that challenge received wisdom and existing practices. Later on, however, when a new technological system comes into its own, the regime can have an enabling role. A characteristic of the macro level is that it responds to long-term trends and developments. However, this does not mean that individual actors (individual farmers, agricultural farms, local government) cannot be a catalyst for the transition process. Certain innovations in technology, behaviour, policy and institutions do break out of the niches of the micro level, if they stabilise into a promising design around which learning processes take place (Rotmans *et al.* 2001:20). For this to occur successfully, strategies and expectations, and a social network need to take form and become stabilised (Hoogma 2000). With the proliferation of the design comes a support basis – and, as a result, the momentum for take-off at the meso and macro levels. Alternatively, developments at the meso and macro levels (e.g. institutional changes, changes to regimes, belief changes) can also stimulate a take-off at the micro-level.

Regimes change as a result of internal conflict or external pressure, sometimes in response to bottom-up pressures from the micro level. Regimes may take a defensive approach, a reactive approach (seeking improvements within the present system) or an innovative approach by contributing actively to a transition. Over the course of time they may adopt all three. The multilevel aspect of transitions implies that change only occurs if developments at one level gel with those in other domains. But there must also be interaction between developments at the micro, meso and macro levels if the transition process is to occur (Rotmans *et al.* 2001:20). The next section describes in more detail the mechanisms and patterns underlying these transition processes.

Socio-technical dynamics of innovation processes: patterns and mechanisms

The previous section explained what transition processes are. In this section we address the questions of how transitions come about and whether we can distinguish particular patterns and mechanisms in transition processes. The focus on patterns and mechanisms, rather than on particular technologies, is needed because sectoral innovations (for instance, in agriculture) are not related to a single technology that is in need of replacement or alteration, but to a range of technologies, that are interconnected which each other and with the social system in which they are put to use. For example, changes in the agricultural sector are related to a broad range of influences, including the availability of energy and other resources, what and how people eat and, how and where that food is processed, distributed and marketed. In addition to this view which takes into account the whole supply and consumption chain it must also be borne in mind that agriculture has to compete with other policy concerns, such as economic, environmental and spatial planning.

Arentsen *et al.* (2002) provide a useful conceptual model of the major stages in the transition of socio-technical regimes, which seeks to take these broader features into account. They identify three main phases of transition within socio-technical regimes:

1 *Dynamic stability*. This stage represents a congruent dynamics in and amongst all of the dimensions of the regime. The regime is in a stage of dynamic stability because the ongoing dynamics in all dimensions are in accord with each other and mutually supportive in their development. The knowledge base of the regime produces new technologies incrementally, improving incumbent technologies so that they smoothly integrate into the regime. Changes and developments in the regime increase its dynamic stability.

2 *Friction*. This stage represents incongruent dynamics among the dimensions of the regime that create internal tensions. There are many causes of such frictions: for instance an incongruence between the dominant form and the dominant function of a technology. By technological form we mean the design and construction of artefacts, their components and their integrated performances. Technological

function refers to the meaning of technology to its users: as a 'tool' that must satisfy certain physical, social, economic or cultural needs. Form and function can be either balanced or unbalanced. A change in the policy setting, economic environment, or in the knowledge base may cause friction within the regime.

3 *Dynamic instability.* In this stage, the ongoing dynamics within different dimensions takes on diverse and sometimes divergent courses. The regime enters a state of flux, and the direction of future developments becomes unclear. The functional need for technology remains but it is unclear how the other dimensions will shift in order to satisfy functional needs. The regime may develop into a new stage of dynamic stability. At this point a transition in the regime can be said to have occurred.

Who or what are the agents of change involved in transforming regimes? Actors and actor network configurations play an important role. All actors operating in the context of a socio-technical regime are part of various networks (e.g. research networks, user groups, suppliers, producer networks, financial networks and social groupings) and their everyday decisions and activities mould and shape socio-technical change without them necessarily being aware of this. They all act in a seemingly uncoordinated way, motivated and guided by the economic logic of the market, the political logic of the bureaucracy or the scientific logic of the laboratory. A variety of incentives, past experiences and future expectations, motivates and influences these actors in their decisions and activities which, in turn, almost invisibly mould and shape socio-technical change. Yet these actors are not merely passively influenced by external forces. They also try to shape and influence the outside world, according to their own interests. They develop and maintain networks with other organisations or actors in order to increase access to, and control over, the resources required to achieve their specific goals. They develop coalitions and strategic alliances to maintain and improve their position vis-à-vis resources and the market. It is this complex web of actions and interactions that fuels socio-technical changes in regimes. In order to understand the stability and dynamics of regimes it is important to distinguish between the attributes of actors and those of interactions between actors.

Socio-technical developments are always context bound, but it is possible to trace patterns, regularities and major drivers within the transition process. Modulation options can be derived from the co-evolutionary, multi-level perspective on socio-technical change. The concept of modulation options was initially expounded in Rip and Kemp (1998), and subsequently applied by Geels and Kemp (2000). In this context actor-oriented modulation describes the process of influencing the existing ideas and perceptions of actors, through providing new points of reference for innovation and technical change (e.g. strategic communication of new ideas about desired future developments). In the following paragraphs we describe several specific features of transition processes that have a potential to act as entrance points for modulation.

One modulation option, that takes technology as its point of reference is the 'promise-requirement' cycle of perceptions and expectations. This modulation option makes explicit the interaction between variety and selection and actively tries to anticipate the creation and selection of the desirable forms of technology. One way of organising this kind of modulation is to explicitly identify the functional requirements that new technologies are assumed to address in the future and to organise and manage innovation in response to these findings.

Cross-technical linkages and hybrid forms occur when one emergent form of technology is transferred to another context. The importance of such linkages is clearly illustrated by the example of the transition from horse-based transportation to cars in the early 20th century (see Moors and Geels 2001). The development of vehicles with internal combustion engines was built upon the knowledge and experiences gained from the bicycle, gas-engine and horse-drawn coach transport regimes. The later introduction of the electric starter provides an interesting example of a positive cross-technical influence: one that accelerated the technological trajectory of gasoline cars by borrowing an element (batteries and high voltage ignition) from electric vehicle technology. Incidentally the study of electric vehicles (ibid.) showed a high level of cross-fertilisation between military technology knowledge and the development of the electric vehicle. Many hybrid forms emerged, combining the knowledge and competencies of the dominant internal combustion transport regime with the potential emerging from new electric vehicle regime. Further examples of cross-technical influences and hybrid forms in technological developments in industrial metals production can be found in Moors (2000).

Accordingly, hybrid forms may be an important transitional element, which helps society to move to achieve a transition towards a new regime. The word 'transitional' does not just mean temporary. Hybrid forms may have a 'pathway' function and can catalyse complex, differentiated interactions which in turn generate an accumulation of niche developments. These new technical developments compete with the old technologies via the same niche accumulation mechanisms (i.e. alignment, cross technical influences and hybrid forms), and in the end may destabilise the old regime, opening it up for new technico-institutional designs of development External factors also significantly influence these transitions. Changes in the socio-technical landscape (e.g. changes in prices, values, belief systems, politics or trade) open up new spaces for

innovation and set overall directions for a technological regime. Increasing awareness (amongst farmers, consumers, policy makers and environmentalists) of the unsustainability of current agricultural practices is leading to a renewed interest, amongst these different actors, in 'alternative' agricultural practices. As these alternatives gain momentum new possibilities emerge, which in turn generate new opportunities.
An important feature of agricultural systems, which sets them apart from other technological regimes is the very high degree of heterogeneity that exists within them. Despite fifty years of modernisation which has, amongst other things promoted uniform solutions to the problems faced by farmers, there still exists a great variety of farming styles, strategies and mixes, even within any given region (Van der Ploeg 2003). In addition agriculture remains one of the few economic activities in which resources and decision making capabilities ('the means of production') are widely distributed amongst, mostly, family owned units (as opposed to being concentrated in relatively few companies). Both these factors facilitate the opportunities for the evolution of multiple and decentralised learning processes. Local agro-ecological and cultural circumstances can necessitate and/or act as a catalyst for engendering unique responses and developments. In some instances these may only be appropriate to the locations where they were developed, but in other examples they may well prove to be transferable. Such variety provides an important resource for achieving evolutionary change and has the potential to be strategically exploited for broader regime shifts and transition processes (Kemp and Moors 2002).

In summary, transition processes can be regarded as gradual and multi-faceted processes in which cross-technical influences, hybrid forms and the identification, and active stimulation, of pathway technologies all play an important role. Furthermore, the socio-technical regime is shaped by wider, external, developments in the socio-technical landscape, which create opportunities for change and define directions for development. Agriculture exhibits a great heterogeneity in terms of its practices and user needs and this is a potentially valuable resource for developing socio-technological regimes that are more closely aligned with the principles of sustainability.

The mechanisms of change and modulation options provide some clues as to how we might work towards an agricultural regime shift that is more closely aligned to sustainability criteria. This could be achieved through the use of strategic niche management. The next section presents the main characteristics of strategic niche management.

Strategic Niche Management

Arguments concerning the unsustainable character of modern agricultural practices are well rehearsed. Adverse impacts of modern day agricultural systems include water and soil pollution; nuisance from noise and odour; animal welfare issues; growing consumer concerns over the safety of intensively produced food; the growing distance that food travels from farm-gate to fork; overuse of land for growing animal feed; mad cow disease and other epidemics, destruction of valued habitats and landscapes through overproduction; and the repression of possibilities for small-scale farmers to build their own agricultural communities. At the same time, as part of a quest for sustainable agriculture, new and interesting ideas about alternative technological, organisational and social solutions to modern agriculture systems are emerging. These have mostly been developed by small groups of farmers, developing novelties and prototypes and experimenting with promising alternatives. In practice, many farmers already practice various forms of 'downgrading', (i.e. through low-external input or 'economical' farming) in order to adapt their particular farm better to the prevailing ecological and/or economic situations in which they operate. Downgrading is also adopted as a strategy when farmers try to adapt their farming business to the peculiarities of the products that they produce, or to their preferred farming strategies. In situ experimentation with novelties and local knowledge play a crucial role here. The inventiveness of farmers gives rise to an impressive range of, sometimes astonishing, novelties (e.g. Mango 2002; Wiskerke 1997; Wiskerke *et al.* 2003). However, within the context of the prevailing, dominant agricultural regime, many of these practices remain isolated hidden novelties. These new technologies and associated agricultural practices have not (yet) led to larger changes in the ways in which agriculture is organised and governed. Somehow the adoption and diffusion of these initiatives does not receive adequate support and does not percolate up to the guiding and governing organisations. Strategic Niche Management can provide a management tool to address this deficiency.

Strategic Niche Management (SNM) is about the creation, development and controlled break-down of niches for promising new technologies and concepts. This is achieved through setting up experiments which aim to demonstrate their desirability (for example in terms of sustainability), ways in which they can be improved, and to enhance their rate of diffusion (Weber *et al.* 1999; Hoogma *et al.* 2002). SNM should be regarded as a tool for building niches for novelties, mainly through smart experimentation. SNM provides an opportunity to explore and learn, in a quasi-controlled manner, about the practicality of an innovation outside the R&D setting in which it was initially developed. When novelties come out of their R&D stage they can be seen as fluid options, which embody a number of assumptions about how the technology can be best used and under which conditions. At this stage the design of a technology and the assumptions about how it will be used are in need of further testing. Such testing will result in a better specification of the design itself, as well as identifying user needs and conditions.

Many innovation studies have pointed out that appropriate testing requires the active inclusion of users, policy-makers, researchers and, in some cases, representatives of the general public. They also argue that testing should be viewed as a learning process in which the potential of a new technology is articulated and accepted, amended or rejected. These potentials will include design features, system changes, user characteristics, values associated with its use and policy preconditions.
Accordingly, testing is a process of articulating, specifying and sharing a set of expectations and visions of the potential of a new technology. This process can also generate the emergence of a strong network of actors willing to invest in, and carry a new technology forward. These processes should ultimately lead to the development of better technologies and, possibly, a much smoother diffusion process, since a better fit is achieved between the technology and its social environment (Weber *et al.* 1999). Such experimentation can generate insights into user requirements, desirable design modifications, support measures and likely environmental effects. Such experiments also represent a first step towards the development of a niche for new developments.

A niche can be defined as 'a specific application domain (habitat) where actors are prepared to work with specific functionalities, accept teething problems, higher costs, and are willing to invest in improvements of a new technology and the development of a new market' (Hoogma *et al.* 2002). Developing a niche involves exposing the innovation, on a step-by-step basis, to real-world conditions. It involves a second stage of interaction with users, that of learning about constraints and requirements. This occurs in an environment that is less isolated than the experimental one. If successful, a novelty might move from the original niche to follow-up niches resulting in a process of niche branching*. The first niche often provides the resources to sustain the innovation; the time, capabilities, knowledge, and finance for a network to emerge that is able

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* Rip (1995:418) described the process of *niche branching* as follows: 'Technological change is not a continuous process along dimensions of increasing functionality. It is more like a patchwork quilt or, if one prefers, a different metaphor, the way yeast cells grow. Developments branch off in different directions, cross-connections and interactions occur, and niches, that is limited and relatively easy or advantageous domains of application and further development, strongly determine what steps can be taken productively. The eventual shape of a technology, its usage and the way it is embedded in society can be very different after 5, 10 or more years than it looked at the beginning.'

to produce and use the new technology. From this first niche, a number of new niches can be developed. This process of niche cumulation and niche branching includes the emergence of new application domains and the creation of a 'bandwagon' effect (that is a wider diffusion) through replication of the niche elsewhere (Hoogma *et al.* 2002:24). Eventually novelties may come to compete head-on with the dominant technological regime within its own markets.

Smart experimentation and subsequent niche formation do not automatically lead to regime shifts or radical change. They can lead, first, to a long process of niche proliferation – that is, a process of continued protection. In some cases market niches may develop without further protection and regular market transactions will prevail. More rarely the proliferation, over a number of years, of technological niches (protected spaces) and market niches may result in a regime shift, i.e. a shift in the technological foundation and in agricultural patterns. Such a broad change cannot be brought about by niche development only, or by SNM. If it takes place, it will be the result of a combination of successful SNM, niche development and a set of other factors. These might include the exhaustion of perceived technological opportunities within the dominant regime, a dramatic change in government policies and/or the emergence of a new set of values that incorporate sustainability. SNM is a crucial aspect of this complex process, setting in motion a transition path that nurtures sustainable technologies and allows them to grow (Hoogma *et al.* 2002).

Successful niche development: quality of learning and institutional embedding

Hoogma *et al.* (2002) identify two measures for evaluating the success of early niche development: quality of learning and quality of institutional embedding. Learning refers to a range of processes through which actors articulate relevant technology, markets and other properties. It is called a learning process because the outcomes are not known beforehand, but have to be worked through, by the actors themselves. Learning involves a number of aspects (Hoogma *et al.* 2002:28):

- *Technical development and infrastructure,* which includes learning about design specifications, required complementary technology and infrastructure;
- *Development of user context,* which includes learning about user characteristics, their requirements and the meanings users attach to a new technology and the barriers they encounter in their use;
- *Societal and environmental impact,* which entails learning about the health, safety, cultural and environmental aspects of a new technology;
- *Industrial development,* which involves learning about the production and maintenance network needed to achieve a broader diffusion;

- *Government policy and regulatory framework,* which involves learning about institutional structures and legislation, the government's role in the introduction process, and possible incentives to be provided by governments to stimulate adoptions.

Learning can occur at a number of levels. It may be limited to first order learning. That is when various actors within the niche, learn about how to improve the design to make it more acceptable to users and about ways of creating a set of policy incentives that will accommodate or encourage adoption. However, for niche developments to lead to a regime shift, a different kind of learning process is needed, second order learning. Here concepts about technology, user demands and regulations are not only tested, but also questioned and explored. Opportunities emerge for co-evolutionary dynamics, that is the mutual articulation and interaction of technological choices, demand and possible regulatory options. Co-evolutionary learning also allows for, what Wynne (1995) calls 'collective value learning', that is clarifying and relating the various values of producers (designers), users and other involved parties, such as governments. Thus successful niche development involves first order learning in a wide array of areas (see above), as well as the occurrence of second order learning.

The emergence of a new socio-technical regime will change the selection environment for innovation. Earlier processes of niche development will proceed this change, thus paving the way for broader change through a process of institutional embedding: Three crucial aspects of institutional embedding can be identified:

- Institutional embedding gives rise to complementary technologies and the necessary infrastructures, a necessary factor for increasing adoption in later diffusion phases;
- Institutional embedding produces widely shared, credible (i.e. supported by facts and demonstrated successes) and specific expectations;
- Institutional embedding enlists a broad array of actors aligned in support of the new regime. This network includes producers, users and third parties, such as government agencies and investors.

Alignment describes a situation in which the actors have developed a stable set of relationships and can readily mobilise additional resources from within their own organisations, because the network has come to be regarded as an important, credible and strategic operation. In such situations, so called 'macro-actors' (Rip 1995:426-427) often emerge, who have a specific responsibility for developing and maintaining harmony and a sense of common purpose within this alignment. Accordingly, successful niche development assumes the development of complementary technologies, more robust expectations and a broad and strongly aligned network (Hoogma *et al.* 2002:28-29).

Market niches and technological niches

Niches can be market niches, in which a novel technology has specific (promised) advantages over the established technology. These advantages are quickly recognised by producers and users and the technologies generally emerge in a bottom up manner. Other promising new technologies may emerge in top-down fashion, in proto-market or technological niches.

Technological niches may promise specific advantages but these are unsubstantiated or only partially recognised or accepted by some actors within the network. Often, the activities associated with developing this kind of niche will be geared towards identifying and testing assumptions about these advantages. Technological niches come about through experiments, pilot and demonstration projects. Four distinct possible outcomes of SNM (and the further development of niches), can be distinguished for technological niche development:

1 The technological niche remains as such. Follow-up experiments are set up to further test the applicability, relevance or desirability of the innovation. This might involve branching to new application domains or replication in similar domains. Technological niche gestation might lead to expansion and scaling-up of the niche in a context that was not originally anticipated.
2 The technological niche becomes a market niche. New experiments are no longer necessary as users start to recognise the advantages of the novel technology and suppliers are willing to invest in production on a small scale.
3 The market niche expands and branches out in new directions, leading to the emergence of new market niches.
4 The extinction of the technological or market niche. The novel technology fails to attract further support and becomes (again) a (this time, less-promising) R&D option. Niche extinction does not necessarily imply that investments are lost. Spill over effects, in terms of network development, technical learning, and improved reputations are some of the benefits that can emerge from a 'failed niche'. Learning that a certain technology development is not desirable is also an important part of SNM.

To sum up, SNM should be regarded as a management tool, which can contribute to successful niche creation for novelties. Its main benefits lie in overcoming barriers to diffusion by exploiting niche dynamics. The SNM approach puts learning processes to the fore, with the result that it is difficult to be specific about outcomes beforehand. Put another way, SNM is about changing the processes of change: introduction processes are designed in a different way. The long-term goal of SNM policies is to create new rules and routines (or what neo-institutional economists would call 'institutions'). These facilitate the earlier and more frequent anticipation of impacts, user requirements and related technical choices. They also foster processes that are specifically designed to stimulate learning and reflexivity, and create space for experimentation. In the long run, the ability to deal with difficult and complex processes will become more widespread.

This book focuses on various agricultural niches, where favourable (but mutually contrasting) conditions, make it possible to go beyond the impasse that often exists between novelty production, on the one hand, and the dominant agricultural regime, on the other. Such situations permit Strategic Niche Management. This book draws upon examples of interesting novelties, illustrating how scientific expertise and institutional design capacity can be combined and contribute to improved farming models (regimes). In all of these examples these models are based upon the principles of low external input farming. They embody a well-thought through and structured move towards less intensive and more sustainable farming practices.

Transition management

Whereas SNM can be understood as a tool or approach to set a transition path into motion, transition management can be viewed as a comprehensive framework for achieving a coherent and integrated move towards a desired future state (e.g. sustainable agriculture). Transition management encompasses multi-dimensional change of a socio-technical regime. The final section of this chapter addresses questions of whether, and to what extent, transition processes can be consciously managed.

Experience shows that a command-and-control approach is not a feasible option for addressing the problems of complex socio-technical systems, such as the current agricultural regime. The non-malleability of technology means that governments cannot simply 'call up' desirable technologies through legislation. Incentives and constraints (including regulation) do have effects (in proportion to the level at which they are introduced), but governments cannot control the level of effectiveness or timing of these. Thus, there is a dilemma of control, identified by Collingridge (1980) who noticed that governments have the greatest influence over technological choices when they are in their infancy and when least is known about their impacts and desirability. When the technology becomes more fully developed and more widely used, it becomes more difficult to control it, because of vested interests and high adjustment costs. This should not be taken to mean that technology becomes out of control, but rather that the dynamics of control do not always lead to universally acceptable outcomes (Rip and Kemp 1998). Accordingly, a different type of approach is needed, which we might call modulation. Modulation policies are oriented at the dynamics, structures, strategic games and learning. They imply new roles for governments: those of 'alignment actor', matchmaker and facilitator of change (Rip and Kemp 1998; Kemp 2000). This in turn leads to a different set of policy recommendations. A modulation strategy does not imply abandoning traditional policies of regulation and taxation but places more emphasis upon long-term transition goals and regime shifts (system innovations). Within a modulation strategy policy instruments should be fine-tuned to the context in which they are applied. Different instruments are effective at different phases of the transition process. In the pre-development phase, policy should stimulate variation and societal discussions about sustainable agriculture. Once the more attractive solutions and configurations have been identified, it should stimulate investments and the integration of new technologies within existing regimes (via cross-technical linkages and hybrid forms). Public planning and system management designed to control the side effects of new niches and regimes are important instruments later in the transition phases. In general, there is a need for both generic and technology-specific policies (Kemp 2000; Arentsen *et al.* 2002; Kemp and Moors 2001).

Examples of modulation policies have been described under the label of transition management in Rotmans *et al.* (2000, 2001). Kemp and Moors (2001) provide a number of suggestions of strategies for transition management, which we discuss below:

- *Engagement in the use of social experiments and creation of niches for promising technologies (Strategic Niche Management).* At the early phase of development, new technologies need protection from the selection environment. Without protection new technologies face difficulties in coming into their own. However, this protection should be partial, temporary and phased out. This fosters interactive learning and institutional adaptation which are necessary for pushing the transition process forward. Government policy can assist with this process. By focussing on local opportunities afforded by special circumstances a transition path may be created in a bottom-up, non-disruptive manner. Particular support should be provided to 'pathway technologies', those technologies that help to bridge the gap between the current regime and a new one, thereby helping to avoid lock-in. (see Hoogma *et al.* 2002).
- *Stimulation of pathway technologies.* How can such pathway technologies be stimulated? It is important to explore a wide range of new agricultural systems as they may generate a diverse range of benefits

and because, as a general principle, society should not place all its eggs in one basket. The need for stimulation and the forms that it takes should be regularly assessed, and policies should be flexible. To increase the chance of a transition occurring and to make sure that the path chosen is the best one, different paths should be explored, together with the possibilities for positive cross-linkages, cross-influences and cumulative effects..

- *Focus on routes of niche accumulation that may lead to regime changes.* Transition cannot be guided and managed unless there is a transition path. However there is not just one path but many possible paths of which it is impossible beforehand to tell which one is the best (if there is a best path at all). There is a need to identify all possible paths and to explore these. By creating a little bit of irreversibility in the desired direction (e.g. towards downgrading in agricultural practices) a new path or trail may be created. To identify or create this 'desirable' trail, it is necessary to evaluate the present agricultural regime and the possibilities that exist to shift it towards more sustainable directions. This implies the need to identify opportunities to influence niche branching. Active stimulation of the development of hybrid forms and pathway technologies act as interludes between the old and new regime and could facilitate transitions to a new agricultural regime. One should consider interrelationships between different developments. Cross-technical influences may provide a momentum for development. Thus, the focus should be on experimenting with a wide range of niche agricultural technologies, which in the long-term could serve as stepping stones for a new agricultural regime. The experiments should be more than just demonstration projects. They should be set up in such a way that suppliers and users both learn about the new possibilities. Basic assumptions and existing expectations should be tested through second order learning.
- *Modulation of 'promise-requirement cycles' of perceptions and expectations.* New technologies have been characterised as 'hopeful monstrosities' (Mokyr 1990). They hold promise, but are still under -developed in terms of user requirements. The requirements themselves may not yet be clear or be in state of flux. This calls for the need to stimulate 'promise-requirement' cycles and to mobilise the resources necessary to build a forceful agenda (for development work in the technological niches) in which general, societal, interests strengthen and support the private and short-term interests of individual actors. Promise-requirement cycles may give rise to new markets, opening up the possibilities for wider (external) changes.

Transition management as an integrative framework

The above actions should be pursued as part of an overall transition endeavour and not as isolated actions. They are best undertaken as part of a structured 'total transition' programme with discrete rounds of development in which progress is assessed and goals and instruments are evaluated (and adjusted) through the use of a transition agenda. Transition management then becomes a collective, co-operative effort to work towards a transition in a step-wise manner. Three key elements of transition management are:

1. The establishment of a transition goal, based on visions of sustainability (e.g. downgrading).
2. The use of societal experiments with technological options that fit with this vision.
3. The use of development rounds in which policies and transition goals are reassessed and redefined.

Transition management involves the use of a wide range of policies, the timing of which needs to be gauged to the particular circumstances of transition phases and external developments. It does not offer a step model to get to state Y via steps X1 to Xn. Some policy interventions, such as the exploration of many solutions in the pre-development stage, and policies towards system integration in the take-off stage, are stage specific. Others, such as the periodic reassessment of goals, visions and policies, are recurrent. Other policies, such as the internalisation of external costs, and support of science and technological research for sustainable agriculture should be continual and ongoing. Transition management differs from the more traditional approach of planning and implementation. It does not operate on the basis of a blueprint, but on the basis of a set of goals (or quality images). These goals are not fixed and the policies to further the goals are constantly assessed, and periodically adjusted, in development rounds. This creates some flexibility while maintaining an overall sense of direction. Through its focus on long-term ambitions and its attention to dynamics transitional management aims to overcome the conflict between long-term ambition and short-term concerns. Learning, maintaining variety and institutional change are important policy aims. Transition management does not only consist of instruments, but is also about ways of interacting and the mode of governance which, in the case of agriculture, has to develop new technico-institutional designs. It is important that outsiders should be involved in the transition process, that there should be commitment to change and clear objectives and that the transition endeavour should be institutionalised. All this does not provide a guarantee of success, but it does increase the chances of a transition towards a new, downgraded, agricultural regime actually occurring.

References

Arentsen, M. and Künneke, R. (1996) Economic organization and liberalization of the electricity industry, *Energy Policy* 24(6), pp. 541-552

Arentsen, M., R. Kemp, and E. Luiten (2002) Towards a climate neutral society, in: M. J. T. Kok, W. J. V. Vermeulen, A. P. C. Faaij and D. d. Jager (Eds.), *Technological Change and innovation for climate protection: the governance challenge,* Earthscan Publications Ltd, London, pp. 59-82

Arentsen M. and J. Eberg (2001), *Modulation of Sociotechnical Change as Climate Change Challenge.* Report for Dutch National Research Programme on Global Air Pollution and Climate Change (report no.: 410 200 100 (2001), Twente University, Enschede, The Netherlands.

Collingridge, D. (1980), *The Social Control of Technology,* London: Pinter.

DeSanctis, G. and M.S. Poole (1994). Capturing the complexity in advanced technology use: adaptive structuration theory, *Organization Science 5,* pp. 121-147

Dolfsma, W., F. Geels, R. Kemp, E. Moors (ed.), A. Rip (1999), *Management of Technology Responses to the Climate Change Challenge: Theoretical Elaboration of the Co-evolutionary 'Technology-in-Society'Perspective,* Deliverable 1 for the Dutch National Research Programme on Global Air Pollution and Climate Change, University of Twente: Report No. CSTM 116.

Dosi, G. (1982), 'Technological paradigms and technological trajectories: a suggested interpretation of the determinants and directions of technical change', *Research Policy 11,* pp.147-162.

Ende, J.van den (1994), *The Turn of the Tide. Computerization in Dutch Society, 1900-1965.* Delft: Delft University Press, PhD Thesis.

Geels, F. and R. Kemp (2000), *Transities vanuit sociotechnisch perspectief – Achtergrondrapport voor het vierde Nationaal Milieubeleidsplan (NMP-4),* Universiteit Twente en MERIT, November 2000, 63 pp.

Geels, F. (2001), *'Technological transitions as evolutionary reconfiguration processes; A multi-level perspective and a case-study',* paper for ECIS Conference on 'The Future of Innovation Studies', Eindhoven University of Technology, The Netherlands, 20-23 September 2001.

Hoogma, R. (2000), Exploiting technological niches: strategies for experimental introduction of electric vehicles, Enschede, Twente University Press, PhD Thesis.

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

Jansen, J.L.A. (1993), 'Towards a sustainable future, en route with technology!' in : *CLTM: The Environment: Towards a Sustainable Future,* Dordrecht, Kluwer Academic Publishers 1993, pp.497-525.

Kemp, R. *et al.* (1994), *Technology and the Transition to Envrionmental Stability: Continuity and Change in Complex Technological Systems.* Final report for SEER research programme of the Commission of the European Communities. Maastricht/The Netherlands: Maastricht Economic Research on Innovation and Technology.

Kemp, R., J. Schot, and A. Rip (1997), '*Constructing transition paths through the management of niches*', paper presented at 'Path creation and dependence' conference, Copenhagen 19-22 August 1997.

Kemp, R., J. Schot, and R. Hoogma (1998), 'Regime shifts through processes of niche formation: the approach of strategic niche management', *Technology Analysis and Strategic Management* 10, pp. 175-196

Kemp, R. (2000), 'Technology and Environmental Policy – Innovation effects of past policies and suggestions for improvement', *OECD proceedings Innovation and the Environment*, OECD, Paris, 35-61

Kemp, R. and E.H.M. Moors (2001), '*Modulation dynamics in transport for climate protection*', Paper presented at the conference 'Institutions and instruments to control global environmental change', Maastricht, June 2001, organised by METRO.

Kuhn, T. (1962), *The Structure of Scientific Revolutions*. Chicago: Chicago University Press.

Latour, B. (1992), 'Where are the missing masses? The sociology of a few mundane artefacts. In: W.E. Bijker and J. Law (eds.) *Shaping Technology / Building Society*. Cambridge and London: MIT Press, pp. 225-258.

Mango, N.A.R. (2002), *Husbanding the Land: Agriculural Development and Socio-Technical Change in Luoland, Kenya*, PhD thesis, Wageningen University

Marvin, C. (1988), *When old technologies were new: thinking about electrical communications in the late ninetheenth century*. Oxford: Oxford University Press.

Mokyr, J. (1990), *The Lever of Riches*, New York: Oxford University Press.

Moors, E.H.M. (2000), *Metal Making in Motion. Technology Choices for Sustainable Metals Production*. Delft: Delft University Press, PhD thesis.

Moors, Ellen H.M. and Frank W. Geels (2001), *Dynamics of Sociotechnical Change in Transport and Mobility. Opportunities for Governance*. Report for Dutch National Research Programme on Global Air Pollution and Climate Change (report no.: 410 200 071 (2001), Centre for Studies of Science, Technology and Society, University of Twente, Enschede, The Netherlands.

Moors, E.H.M. and K.F. Mulder (2002), 'Industry in Sustainable Development. The contribution of regime changes to radical technical innovation in industry,' forthcoming in *International Journal of Technology, Policy and Management*, No 2, June 2002.

Nelson, R.R. and S.G. Winter (1977), 'In search of a useful theory of innovation', *Research Policy 6*, pp.36-76.

Ostrom (1990), *Governing the Commons: The Evolution of Institutions for Collective Action*. New York: Cambridge University Press

Ostrom (1992), *Crafting Institutions for Self-Governing Irrigation Systems*. San Francisco: Institute for Contemporary Studies Press

Ploeg, J.D. van der (1999), *De Virtuele Boer*, Van Gorcum, Assen

Poel, I. van de (1998), *Changing Technologies. A comparative study of eight processes of transformation of technological regimes*, Twente University Press, Enschede, PhD Thesis.

Rip, A. (1995), 'Introduction of New Technology: Making Use of Recent Insights from Sociology and Economics of Technology', *Technology Analysis and Strategic Management* 7(4), pp. 417-431.

Rip, A., T.J. Misa, and J.W. Schot (eds.) (1995), *Managing Technology in Society*. The Approach of Constructive Technology Assessment. London: Pinter Publishers.

Rip, A. And R. van de Velde (1997), *The dynamics of innovation in bio-engineering catalysis. Cases and analysis,* Seville: European Commission Joint Research Centre, Institute for Prospective Technology Studies, May 1997, Technical Report Series EUR 17341 EN.

Rip, A. and R. Kemp (1998), 'Technological Change', in S. Rayner and E.L. Malone, *Human Choice and Climate Change – An International Assessment,* Vol 2, Batelle Press, Washington DC 1998, pp. 327 – 399.

Rip, A. and J.W. Schot (1999), 'Anticipating on Contextualization – Loci for Influencing the Dynamics of Technological Development', in: D. Sauer and C. Lang (eds.), *Paradoxien der Innovation: Perspektiven Sozialwissenschaftlicher Innovationsforschung,* Frankfurt: Campus Verlag Frankfurt.

Rogers, E.M. (1994), *Diffusion of Innovations,* Free Press, New York

Rotmans, J., R. Kemp, M. van Asselt, F. Geels, G. Verbong and K. Molendijk (2000), *Transities and Transitiemanagement: de casus van een emissiearme energievoorziening,* Onderzoeksrapportage t.b.v. NMP4, ICIS and MERIT, Universiteit Maastricht, Oktober 2000, 79 pp.

Rotmans, J., R. Kemp, M. van Asselt (2001), ' More evolution than revolution: transition management in public policy', *Foresight Vol 3, No 1,* pp. 15-31.

Schot, J., A. Slob, and R. Hoogma (1996), *De invoering van duurzame technologie: Strategisch Niche Management als beleidsinstrument,* DTO werkdocument CST3.

Schot, J. and A. Rip (1997), 'The Past and Future of Constructive Technology Assessment', *Technological Forecasting and Social Change* 54, pp. 251-268.

Smits, R., M. Hekkert, H. van Lente (2001), *Intermediairen en Transitiemanage-ment. Nieuwe rollen voor NOVEM?* Report Disciplinegroep Innovatie-wetenschap, Universiteit Utrecht, Juni 2001, 44 pp.

Stoelhorst, J.W. (1997), *In Search of a Dynamic Theory of the Firm. An evolutionary perspective on competition under conditions of technological change with an application to the semiconductor industry,* Enschede: University of Twente, PhD-thesis.

Ven, A.H. van de *et al.* (1989), *Research on the Management of Innovation.* The Minnesota Studies, New York: Harper and Row.

Weber, M., R. Hoogma, B. Lane, and J. Schot (1999), *Experimenting with Sustainable Transport Innovations. A workbook for Strategic Niche Management,* Seville/ Enschede

Weick, C.W. (2001), 'Agribusiness technology in 2010: directions and challenges,' *Technology in Society* 23, pp. 59-72.

Wiskerke, J.S.C. (1997), *Zeeuwse akkerbouw tussen verandering en continuïteit. Een sociologische studie naar diversiteit in landbouwbeoefening, technologieontwikkeling en plattelandsvernieuwing,* PhD Thesis Landbouwuniversiteit Wageningen.

Wiskerke, J.S.C., F.P.M. Verhoeven and L. Brussaard (eds.) (2003), Rethinking environmental management in Dutch dairy farming – a multidisciplinary farmer-driven approach. Special issue of *NJAS – Wageningen Journal of Life Sciences 51 (1-2),* pp. 1-127

Wynne, B. (1995), 'Technology assessment and reflexive social learning: observations from the risk field', in: Rip, A., Th.J. Misa, and J. Schot (eds.), *Managing Technology in Society. The Approach of Constructive Technology Assessment.* London: Pinter Publishers, pp. 19-36.