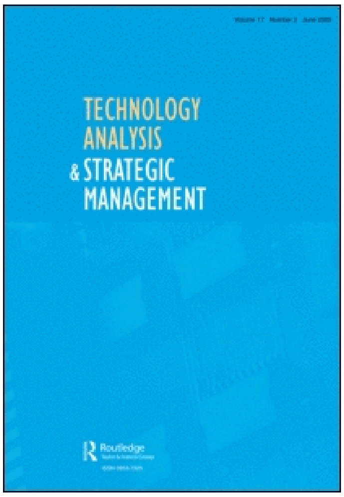

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Regime shifts to sustainability through processes of niche formation: The approach of strategic niche management

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Regime Shifts to Sustainability Through Processes of Niche Formation: The Approach of Strategic Niche Management

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ABSTRACT *The unsustainability of the present trajectories of technical change in sectors such as transport and agriculture is widely recognized. It is far from clear, however, how a transition to more sustainable modes of development may be achieved. Sustainable technologies that fulfil important user requirements in terms of performance and price are most often not available on the market. Ideas of what might be more sustainable technologies exist, but the long development times, uncertainty about market demand and social gains, and the need for change at different levels—in organization, technology, infrastructure and the wider social and institutional context—provide a great barrier. This raises the question of how the potential of more sustainable technologies and modes of development may be exploited. In this article we describe how technical change is locked into dominant technological regimes, and present a perspective, called strategic niche management, on how to expedite a transition into a new regime. The perspective consists of the creation and/or management of niches for promising technologies.*

Introduction[1]

Every new car show features the glorious introduction of environmentally benign vehicles. Examples are electric vehicles powered by batteries, hybrid-electric vehicles with small petrol or diesel engines generating electricity on-board, natural gas vehicles; lightweight vehicles built with composite materials instead of metal and vehicles for public individual transport systems.[2] Only very few of the vehicles are for sale. This raises the question of why such technologies are not introduced into the market-place when their benefits to society are so evident. Is there no market for these technologies? This is what the automobile manufacturers tell us. But why is there no market? Is it because consumers do not want to pay extra for environmental benefits? Or are the reasons political, namely the failure of policy-makers to make environmental benefits an integral part of the structure of incentives and constraints in which people trade and interact? Or is it that manufacturers think that there is no market or find the market for environmentally desirable automobiles less attractive than the market for gasoline automobiles? As we will argue, there is not just one barrier to the introduction of alternative vehicles but a whole range of factors that work against the introduction and diffusion of alternative

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vehicles. The slow diffusion of environmentally preferable technologies is by no means exceptional, although there are extra barriers for clean vehicles.[3]

In the innovation literature, the hard times for new technologies are a common theme. To develop a new idea into a prototype and product means overcoming resistance both outside and inside the innovating organization. It requires a special kind of management: the management of attention, of riding ideas into currency, of managing part–whole relationships (integrating functions, organizational units and resources) and the institutionalization of leadership.[4] In the organization, new innovations often receive lukewarm support. Most innovations do not start out as a strategic activity but as a peripheral activity of a small team of developers, as most of the research and development (R&D) work in the organization is geared towards improving existing products and reducing their production costs. This holds particularly true for automobile development. After an initial period of competing designs in drive trains (roughly 1890–1920), a dominant design emerged which is still the basic design in automobile development. This basic design consists of an internal combustion engine, a metal body and a steering wheel, to name a few salient features. Although the automobile industry is quite innovative, when it comes to increasing vehicle performance, safety and comfort, often by the application of electronics, the basic design is maintained. As to the functional and manufacturing characteristics, most vehicles are multi-purpose vehicles that are produced in highly standardized processes, even though automobile producers have shifted to more flexible modes of production. In the past decade, the model range has been extended, with the very successful minivans (six to eight passenger vans on a car platform) and 'recreational vehicles' or sports utility vehicles (Jeep and pick-up lookalikes), as well as the thus far less successful urban cars (small two-seaters). Although different in their appearance, they do not constitute a departure from the basic design. A possible exception is electric versions of urban cars, for which a small niche market exists in a few countries. The innovations just outlined have generally not been positive from an environmental point of view. Engines have become cleaner and more efficient in the past decade and a half, but added safety features and other accessories and consumer preferences for bigger cars have meanwhile resulted in higher average fuel consumption of cars. The successful minivans and sports utility vehicles, especially, are 'gas-guzzlers'.[5]

The idea of a basic or dominant design is an important notion in the innovation literature. It was introduced by Abernathy and Utterback in their study of technical change in the US automobile, aircraft and electronics industry. In each industry, a dominant design emerged which served as the basis of development work, both inside and outside the industry. It served as a model for development, by defining an outlook or frame of reference for engineers, and enabled standardization, so that production economies can be sought.[6] The idea of a technological framework and shared outlook of engineers was developed further by Nelson and Winter, and Dosi, Nelson and Winter use the notion of a technological regime and Dosi of a technological paradigm to account for the problem-solving activities of engineers.[7]

An important characteristic of the concepts of technological paradigm and technological regime is the existence of a core technological framework that is shared by a community of technological and economic actors as the starting point for looking for improvements in product and process efficiency. It focuses the attention of engineers upon certain problems, while neglecting others. As Dosi writes, "a technological paradigm has a powerful exclusion effect: the efforts and the technological imagination of engineers and of the organisations they are in are focused in rather precise directions while they are, so to speak, 'blind' with respect of other technological possibilities".[8] Although the authors are not very explicit about the causal factors leading to this exclusion effect, they suggest that two factors play a key role: first, the consensus of engineering beliefs and the shared knowledge about the key parameters and binding constraints;[9] second, beliefs as to what the market wants. Thus, unlike biological evolution, variations are not blind. Dosi speaks of *ex ante* selection.[10] This *ex ante* selection takes places when firms anticipate possible selection by the market and a wider set of institutional factors together comprising the selection environment. What is missing in these approaches, however, is an account of how changes in the economic and social environment impact on the research agenda of firms (and other technology actors) and how the selection environment is shaped by old technologies (through the emergence of production routines, existence of infrastructures, the formation of skills and habits, and established consumption patterns). In our view, engineering beliefs and approaches and *ex ante* selection are important elements in the direction of technological change, but as an explanation for the direction and nature of technical change they are incomplete because the issue of the coupling of variation and selection processes is insufficiently developed. In the following we will argue that variation and selection are linked to each other through what we will call a technological regime.[11]

In the next section, we take a closer look at the different factors that affect the development and use of new transport technologies, in particular how they impede a shift to more sustainable transport technologies. In doing so, we focus on the barriers for more sustainable transport technologies. These barriers are discussed individually, although it is the combined occurrence of the barriers that is responsible for the slow transition to more sustainable transport technologies. We then look at technology concepts from innovation theory to explain the slow transition, and offer a critical discussion of the concept of a technological paradigm. We advance the concept of a technological regime, which is used as a key concept in this paper. Then we examine the problem of technological regime shifts and discuss the ways in which technical change may be oriented towards social goals by public policy-makers. We point out the limitations of traditional technology promotion and control policies and the need to take a process approach to orient the dynamics of socio-technical change in socially beneficial directions. The final section describes strategic niche management as a way to manage the transition into another technological regime.

Why Is There Under-utilization of More Sustainable (Transport) Technologies?

Technological Factors[12]

One important barrier to the introduction and use of new technology is that the new technology does not fit well into the existing transportation system. The use of the new technology may require complementary technologies that are perhaps not available (in short supply) or expensive to use. The introduction of battery-fed electric vehicles, for example, will require the development of an infrastructure for charging batteries. It may also be that the technology itself needs to be further developed. In the early phase of their development, new technologies are often ill-developed in terms of user needs and expensive because of low-scale production. They need to be optimized. A related factor is that the new technologies have not yet been tested by consumers on a large scale. Actual large-scale use will lead to redesigning and new, unforeseen design specifications. These technological barriers have been given increased attention over the past couple of years, especially in connection with various experiments with new technologies (electric vehicles, natural gas vehicles, etc.) that are being carried out in various countries.

Government Policy and Regulatory Framework

Government policy may also be a barrier. Even though governments are committed to environmental protection and other social goals, they are often not putting out a clear message that there is a need for specific new technologies. In a sense the signals are conflicting because nearly all new technologies are stimulated by R&D subsidies, even though it is not clear which role they should play in a future transportation system. In none of the countries studied by Elzen *et al.* was there a technology policy based on a clear view of the future to guide technology developers, planners and investors towards sustainable development.[13] The manufacturers therefore remain uncertain about the market developments and will be reluctant to invest in precarious and risky alternatives. Moreover, the existing regulatory framework may actually form a barrier to the development of new technologies. For instance, the very strict safety requirements in the Japanese natural gas law drives up the price of on-board gas cylinders and refuelling stations to five times the level of other countries. The Californian zero-emission vehicle (ZEV) legislation has strongly stimulated the development of electric vehicles but discourages the development of hybrid-electric vehicles, although the latter may be cleaner if the emissions by electricity production plants are taken into account.[14] Adaptations of legislation are often quite cumbersome, partly because some of the actors may oppose them.

Cultural and Psychological Factors

There may also be cultural and psychological factor barriers. In this century, the automobile, with its high speed and the possibility it offers of freedom on the road at any given time, has become an icon of the modern life-style. Values such as flexibility and freedom are associated with the possession and use of a car. For many automobile users, owning and driving a car is a way of expressing their individual and societal identity: their car is an expression of status.

Car manufacturers, consumers and car salesmen have an idea of what a car is and should be able to do. This image may not accord with that of the different alternatives. The unfamiliarity with the alternatives often leads to scepticism beforehand, because the actors mentioned judge the new technology on the basis of the characteristics of the dominant technology. An example is the so-called idle-off device that has been offered by Volkswagen in some of its models. This device shuts off the engine when the car is stationary or slowing down. This may limit fuel consumption in the city by 20–30%, and also strongly reduce emissions. When the car accelerates the engine will restart automatically. The idle-off device has not been a success, because Volkswagen and the dealers do not dare to promote this option. They think that drivers will fear that the engine will not restart, and therefore prefer the certainty of hearing the engine run when stationary.

Demand Factors

There are economic barriers to do with prospective users' preferences, risk aversion and willingness to pay. The new technologies have not proven what they are worth, so consumers are not sure what to expect. The meaning and implications of the new technologies have yet to be specified by their application in practice. New technologies may also not meet the specific demands of consumers, which means that an alteration of these demands and preferences may be required to introduce the technologies. The battery-powered electric vehicle's limited range will force its user to adapt his/her travel patterns. Only a few consumers will accept a lesser performance of the product in return for a lesser environmental impact. The insecurities and aversions of the consumer are sufficient reason for the manufacturers of the new technologies not to market certain new products. This market is very sensitive, and a loss of market share because of the failed introduction of a new product may cause serious problems. The manufacturers of existing technologies prefer to avoid risks by building on current consumer preferences. Automobile dealers, who are supposed to sell the cars to the consumers, are reluctant to promote cars that do not meet traditional consumer preferences.

Another important demand factor is the price of the product. New technologies are often expensive owing to the small scale of production and because they have not benefited from dynamic learning economies on the supply side.[15] The high price that results from the high unit costs of production is quite a disadvantage in the automobile market, where all the major manufacturers compete on price. Even relatively simple new technologies (for example, the pre-heated catalyst[16]) have a hard time on account of their raising of the cost price.

The manufacturers think that consumer demands cannot be changed, and therefore they often refer to them as the most important barriers. Their argument is that they cannot manufacture products for which there is no clearly articulated consumer demand. However, the success story of the minivan in the US undermines this argument. As shown by Porac *et al.*,[17] consumer research in the late 1970s had indicated a widespread sentiment in favour of a small people mover van in the US. The American car manufacturers started development of such a van, but Ford concluded that the vehicle would become too costly and General Motors (GM) considered the market too fragmented. Only Chrysler went ahead in an all-or-nothing gamble in the face of bankruptcy, and hit instant success. Ford and GM then followed. The US minivan market currently comprises unit sales of over one million vehicles. This example does not directly compare to the assumed market for environmentally benign vehicles. The buyers of minivans did not have to settle for less with regard to comfort and performance, battery-powered electric vehicles have limited range and speed, and recharging the battery is very time-consuming.[18]

Production Factors

There are also barriers on the supply side. The development from prototype to mass product is quite a long and cumbersome process, but above all it is a risky process. There may be a chance to develop a new market, but the incentive for the automobile industry to introduce a product to the market is not high when it is far from certain that the consumer is interested in buying it, or when there are no external factors such as legislation that require automobile manufacturers to offer the product for sale to consumers. Investing in new technologies may mean that the sunk investments in existing production facilities will never be gained back. Moreover, existing companies do not want to risk their core competencies becoming superfluous. To the automobile industry, the mass production of cars with combustion engines is just such a core competence. Its organization is aligned to this competence, both technically (in terms of its products, production processes and R&D activities) and organizationally (in terms of modes of control, marketing and strategies). Generally, enterprises may aim their production strategies at: (1) cost leadership; offering products at the lowest price on the market; (2) differentiation, offering exclusive products (for example, of a specific brand) for a large market; or (3) producing for market niches, i.e. producing a limited assortment for a limited group of customers. The major car manufacturers predominantly choose strategy one or two; they have limited or no competence to produce cars for market niches. Therefore, the manufacturers are interested in alternative vehicles only when these can be produced for a big market.

In such a situation it often takes new enterprises to market the new products. These do not stand much of a chance, however, if they are not backed by sufficient capital. This creates an additional problem, since banks are reluctant to invest in risky projects and governments only grant subsidies for R&D and not for marketing a new product. Moreover, the new companies lack the competence to produce large quantities of cars of constant high quality. These factors constitute high barriers for newcomers. Cooperation between newcomers and the existing car industry might be able to change this. A good example is the cooperation between the Swiss company SMH and Mercedes, who intend to introduce a new type of vehicle to the market in 1998. Examples of small companies that have got into major financial problems are the Swedish company Clean Air Transport (CAT) and the American US Electricar. CAT missed an order for 10 000 hybrid vehicles (the prize in a competition organized by the city of Los Angeles) because Swedish financiers did not trust the company's competence. US Electricar was forced to give up the low-profit production of conversion-electric vehicles because of the decreasing value of its stocks. There are, however, more successful examples of new enterprises, such as the French SEER and German Hotzenblitz. For the moment, these companies produce on a small scale, however.

Infrastructure and Maintenance

The introduction of new technologies may require adaptation of the infrastructure. A new distribution system may have to be established, as for natural gas and hydrogen technology, or special provisions may have to be made; for example, for charging electric cars. Another adaptation concerns the maintenance that vehicles require. Mechanics in garages must get acquainted with the new technologies in order to be able to check and repair the new vehicles. A characteristic of infrastructure and maintenance investment is its threshold value: only with a relatively high number of vehicles does it become profitable to create a new infrastructure, although the vehicles require such an infrastructure from the very beginning. Crucial questions are, therefore, who is responsible for the development of the infrastructure and how the initial costs can be covered. Another problem is the so-called sunk investments in the existing infrastructure. The groups in charge of the current infrastructure form a strong lobby for their own interests.

Undesirable Societal and Environmental Effects of New Technologies

New technologies may be able to solve some problems, but they may also introduce new ones. The batteries of electric cars could cause an additional waste problem; some alternative fuels lead to an increase of certain types of emissions; growing crops required for the production of bio-fuels takes up a great deal of land, which prevents the use of that land for other purposes (growing alimentary crops or nature conservation, for example); the availability of cheap and very economic vehicles may cause a rebound effect in the form of an increase in vehicle mileage. Quite an effort will be required to find out if and how such problems can be solved. In the meantime, these problems affect the image and performance of the new technology.

Conclusion

As the foregoing discussion shows, there are many factors that impede the development and use of new technologies, especially systemic technologies that require changes in the outside world. These factors are interrelated and often reinforce each other. What we have is not a set of factors that act separately as a containment force, but a structure of interrelated factors that feed back upon one another, the combined influence of which gives rise to inertia and specific patterns in the direction of technological change. But what exactly is this structure and how does it affect technological choices of technology developers and users? These questions are examined in the next section.

The Structured Nature of Technological Change: Technological Regimes and Paradigms

The existence of patterns in technological change is widely recognized. Examples are miniaturization in microelectronic computers, the use of information technology in manufacturing and offices, the electrification of products and processes and so on. Economists, historians and sociologists have studied these regularities in technological change and have proposed concepts to account for the ordering and structuring of technology. We will describe two concepts that have been highly influential in social studies of technology: the concept of technological regime used by Nelson and Winter and Dosi's concept of technological paradigm.[19]

The concept of a technological regime was coined in the 1977 article 'In search of useful theory of innovation' by Nelson and Winter. In this article, they noted that the problem-solving activities of engineers were not fine-tuned to changes in cost and demand conditions, but relatively stable, focused on particular problems and informed by certain notions of how these problems could be dealt with. Nelson and Winter give the example of the DC3 aircraft in the 1930s, which defined a particular technological regime: metal skin, low wing, piston powered planes. As they write: "Engineers had some strong notions regarding the potential of this regime. For more than two decades innovation in aircraft design essentially involved better exploitation of this potential; improving the engines, enlarging the planes, making them more efficient."[20] Dosi speaks of a technological paradigm, analogous to Kuhn's concept of 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 about where to go, what problems to solve and what sort of knowledge to draw on.

The idea of a core technological framework for industries guiding research activities has gained wide recognition in modern innovation theory. An advantage of this approach is its connection with existing engineering ideas and approaches, which the economic notion of production function fails to make. But as an approach to explain socio-technical change it is too limited, because it focuses too much on cognitive aspects of problem-solving activities and too little on the interplay between cognitive and economic and other social factors that force technological problem-solving in certain directions. This interplay must be perceived as a quasi-evolutionary process of variation and selection, in which the external selection pressures are anticipated by the innovator organization and incorporated into company R&D and production policies; the external selection environment in turn is shaped by the policies of the innovator vendor and a host of other actors who strive to promote (and control) a particular technology.[21] Engineering activities are embedded in larger technological regimes, which consist not only of a set of opportunities but also of a structure of constraints in the form of established practices, supplier–user relationships and consumption patterns. The choice for the internal combustion engine thus depends not just on the prevailing interpretative framework of engineers, but also on the embedding of the combustion engine in engineering practices, production plants and organizational routines, and the embedding of automobiles with internal combustion engines in fuel distribution systems, travel and mobility patterns and automobile repair and maintenance practices.

If we take the quasi-evolutionary dynamics of technical change as a starting point, we need a broader definition of technological regime. A technological regime needs to encompass both the paradigmatic framework of engineers and the selection environment of a technology. The definition of technological regime we use is:[22] "the whole complex of scientific knowledges, engineering practices, production process technologies, product characteristics, skills and procedures, and institutions and infrastructures that make up the totality of a technology". A technological regime is thus the technology-specific context of a technology which prestructures the kind of problem-solving activities that engineers are likely to do, a structure that both enables and constrains certain changes. Within this complex, the accommodation between its elements is never perfect; there are always tensions and a need for further improvement. The term regime is used rather than paradigm or system, because it refers to rules.[23] Not just rules in the form of a set of commands and requirements but also rules in the sense of roles and practices that are being established and that are not easily dissolved. Examples of such rules are the search heuristics of the engineers, the rules of the market in which firms operate, the user requirements to be accommodated at any give time, and the rules laid down by governments, investors and insurance companies. Like a political regime or a regulatory regime, a technological regime contains a set of rules. These rules guide (but do not fix) the kind of research activities that companies are likely to undertake, the solutions that will be chosen and the strategies of actors (suppliers, government and users).[24] The idea behind the technological regime is that the existing complex of technology extended in social life imposes a grammar or logic for socio-technical change, in the same way that the tax regime or the regulatory regime imposes a logic on economic activities and social behaviour. Our definition is thus more in line with the way in which the term regime is used in political science and policy studies.

Technological regimes, in the way we use the term, are a broader, socially embedded version of technological paradigms. A technological regime combines rules and beliefs embedded in engineering practices and search heuristics with the rules of the selection environment. In our view, the restricted (focused) nature of socio-technical change is accounted for in large part by the embedding of existing technologies in broader technical systems, in production practices and routines, consumption patterns, engineering and management belief systems, and cultural values—much more than it is by engineering imagination. This embedding creates economic, technological, cognitive and social barriers for new technologies.

The notion of technological regime defined above also helps to explain why most change is of the non-radical type, aimed at regime optimization rather than regime transformation. It helps to understand why so many new technologies remain on the shelf, especially systemic technologies with long development times that require changes in the selection environment (in regulation, consumer preferences, infrastructure, the price structure). Radically new technologies require changes in both the supply and demand sides, which usually take time and meet resistance, even inside the organization in which they are produced. Firms vested in the old technologies will be more inclined to reformulate their existing products than do something radically new that may involve a great risk to the firm. (For newcomers, the improvement of existing technologies creates an extra barrier for new technologies.) This is not to say that it is just a matter of calculated risk. As noted by Rosenberg and Fransman, firms have a restricted technological horizon and a bounded vision, which serve to focus their exploratory activities upon problems posed by the existing product.[25] As explained, there is a range of factors that work against the development and use of alternative technologies: cognitive (technological paradigms), technological, economic, and social and cultural barriers. This raises the question of how the above barriers may be overcome: how may the technology come into its own, develop from an idea or prototype into a successful product? The next section deals with this question.

The Management of Technological Regime Shifts

In this section, we want to examine how regime shifts occur. While there is no set of general rules, as each transition is unique, historical studies suggest that the following elements are common in technological regime shifts:[26]

- The deep interrelations between technological progress and the social and managerial environment in which they are put to use. Radically new technologies give rise to specific managerial problems and new user–supplier relationships; they require and lead to changes in the social fabric and often meet resistance from vested interests; moreover, they may give rise to public debates as to the efficacy and desirability of the new technology.
- The importance of specialized applications in the early phase of technology development. In the early phase of a radically new technology there is usually little or no economic advantage of the technology; moreover, the existing technologies tend to improve during the development phase (the 'sailing ship' effect).[27]
- These 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 change in such related areas may be of central importance to the viability of the new regime.
- Social views on the new technology are of considerable importance. They include engineering ideas, management beliefs and expectations about the market potential, and, on the user side, perceptions of the technology. These beliefs and views on the new technology are highly subjective and will differ across communities. They also are in constant flux, and the progression of the ideas may be either a barrier or a catalyst to the development of a particular technology.

These elements show that in these technological transitions both the technology and the system in which it is produced and used change through a process of co-evolution and mutual adaptation. Although our understanding of how technological transitions come about is limited, historical evidence suggests that entrepreneurs/system builders and niches play an important role in the transition process.[28] The development of a new technological system is often associated with the names of entrepreneurs. For example, the names of Edison, Insull and Mitchell are associated with the development of the electric system. There was Edison, the inventor–entrepreneur, who built the first electric system, Insull, the manager-entrepreneur, who managed the expansion of the electric system, uniting local systems into larger ones, and Mitchell, the financier–entrepreneur, who introduced financial and organizational means (such as the holding company) by which the growth of the utility systems could continue on a regional level.[29]

A second important factor is the availability of niches or domains for application. Military demand often provided a niche for fledging technologies. Many of the radical technologies of this century (radio, aircraft and computers) depended for their development on money from the military. In other cases, early markets provided a niche. Plenty of examples of niches are available from the history of technology. The steam engine was developed by Newcomen to pump up water from mines; clocks were first used in monasteries where life was arranged according to strict timetables; the origin of the assembly line lies in the armoury of the American army in Springfield, Massachusetts, where the manufacture of muskets was standardized to the extent that all components were interchangeable; and the wheel was first used for ritual and ceremonial purposes.[30] These niches are important for the development of a new technology. Without the presence of a niche, system builders would get nowhere. The niches were instrumental in the take-off of a new regime and the further development of a new technology. Apart from demonstrating the viability of a new technology and providing financial means for further development, niches helped to build a constituency behind a new technology, and to set in motion interactive learning processes and institutional adaptations—in management, organization and the institutional context—that are all-important for the wider diffusion and development of the new technology.

The processes of niche formation occur against the backdrop of existing technological regimes. Often, some of the actors present in these regimes participate and attempts are made to solve problems identified but not solved within the regime. The success of niche formation is, therefore, linked to structural problems, shifts and changes within the existing regime(s). The ultimate fate of processes of niche formation depends as much on successful processes within the niche as on changes outside the niche: it is the coincidence of both developments that gives rise to niche development patterns.

The Problem of Technology Control and Orientation

It may be clear by now that the shift into a new, more sustainable technological regime presents a huge problem for public policy-makers (or anyone else, for that matter). The task is no longer to control or promote a single technology but to change an integrated system of technologies and social practices. The problem is to manage the change process to another regime without creating transition problems. This is the problem that public policy-makers face and must try to resolve. But how do they do this?

The first strategy is to change the structure of incentives in which market forces play. This is the kind of approach favoured by economists. Instead of engaging in the search for technologies to solve specific social problems, policy-makers should change the structure of economic incentives: tax negative externalities and reward positive externalities. The advantage of this strategy is that decisions are made at the decentralized level by individual actors. In this way, environmental benefits can be achieved at the lowest costs. The problem with this approach, favoured by economists, is that the policy measures have to be really drastic to have an impact, considering the dominance of existing technologies. Even the 10-fold increase in oil prices in the 1973–1983 period did not lead to anything more than the marginal use of alternative energy technology—coal and natural gas are still the primary sources for electricity generation and heating, and oil is still the principle transportation fuel. This is not to say that price incentives should not be used. In our view, a carbon tax and tradable permits will have a role to play in the array of necessary greenhouse gas policies, but it is not likely that such measures in themselves will be sufficient to bring about radical change in energy technology unless they significantly raise the costs of using fossil fuels. This is highly unlikely in today's political reality, in which governments are committed to reducing taxes. The recent failure in 1995 to introduce a carbon tax of US$3 per barrel of oil equivalent in the

European Union tells us something about the infeasibility of using taxes to induce technological regime shifts.

The second strategy is to plan for the creation and building of a new socio-technical regime, in the same fashion as decision-makers have planned for large infrastructural works like coastal defence systems or railway systems. The problem with this approach is that in most areas governments cannot really plan for a new technological regime in today's highly differentiated and organized society. The social context in which the new technologies will be used simply defies a planning exercise, even if it is based on a flexible learning by doing approach. Even for firms it is often difficult to plan for successful market introduction. User requirements develop over time in often unpredictable ways.

The third and last strategy is to build on the on-going dynamics of socio-technical change and to exert pressures so as to modulate the dynamics of socio-technical change into desirable directions. For this strategy, the task for policy-makers is to stimulate that the co-evolution of supply and demand produces desirable outcomes, in both the short run and longer term. Rather than laying down requirements, they need to engage in process management to keep the process of socio-technical change going in a desired direction.[31] Such a policy differs from the traditional policy approach, which starts from a stated goal, after which a set of instruments is selected to achieve this goal. Process management does not start from a quantified goal but from a stock of goals. It is aimed at changing the rules of the game, at creating room for experimentation and variation, at shaping the interactions, at making sure that the process is not dominated by certain actors, at learning about problems, needs and possibilities, and at keeping the process of change going in desirable directions. In our view, this is the only feasible way to proceed. Strategic niche management is thus more than a useful addition to a spectrum of policy instruments. It is a necessary and reflexive component of intentional transformation processes of regimes. However, the complexity of the processes involved means that we do not claim this approach to be a panacea. Its success is contingent on many developments outside the reach of policy-makers as well as other actors. We return to this issue later; we first discuss how process management could be done.

Our discussion of technological regime shifts as a process of niche proliferation suggests one possible strategy to manage the transition process: to create temporary protected spaces for more sustainable technologies. These spaces, in the form of technological niches, could function as local breeding spaces for new technologies, in which they get a chance to develop and grow. Once the technology is sufficiently developed in terms of user needs, and broader use is achieved through learning processes and adaptations in the selection environment, initial protection may be withdrawn in a controlled way. As suggested by Schot *et al.*,[32] such policies must be a mixture of three generic strategies: technology forcing, creating and using carrying networks for new technologies (such networks are called technological nexuses) and strategic niche management. The last is particularly interesting for the processes of niche formation. The first two also contribute, but are mainly instrumental in changing the existing regime by making them more favourable (less hostile) to the newly emerging niches. In this article, we focus on strategic niche management.

Strategic Niche Management as a Way to Manage the Transition

From our discussion of continuity and change in technological regimes, strategic niche management emerged as a possible (or even necessary) strategy for governments to manage the transition process to a different regime. The strategy of strategic niche management is, of course, valuable for an actor who wants to push new (sustainable) technologies on to the market. In this paper, we focus on options for government policies. But what exactly is meant by strategic niche management and what are the implications in terms of public policy? In this section, we try to explain what we mean by strategic niche management and how it may be used to induce or accelerate a change in technological regime. We propose the following definition: "strategic niche management is the creation, development and controlled phase-out of protected spaces for the development and use of promising technologies by means of experimentation, with the aim of (1) learning about the desirability of the new technology and (2) enhancing the further development and the rate of application of the new technology."[33]

Strategic niche management is thus a concentrated effort to develop protected spaces for certain applications of a new technology. It is an approach which differs from the old policies. The strategic niche management approach differs from the 'technology-push' approach that underlies most of today's technology promotion policies, by bringing knowledge and expertise of users and other actors into the technology development process and generating interactive learning processes and institutional adaptation. It differs from technology control policies by being aimed at the development of new technologies. The focus on learning is an important aspect of strategic niche management.[34]

The creation of a protected space for a promising technology gives it a chance to develop from an idea or showpiece in an exhibition into a technology that is actually used. The actual use of a new technology is important for articulation processes to take place, learn about the viability of the new technology and build a network around the product. Strategic niche management is more than just an experiment with a new technology, however. It is aimed at making institutional connections and adaptations, at stimulating learning processes necessary for further development and use of the new technology. More specifically, the aims of strategic niche management are:

- to articulate the changes in technology and in the institutional framework that are necessary for the economic success of the new technology;
- to learn more about the technical and economical feasibility and environmental gains of different technology options, i.e. to learn more about the social desirability of the options;
- to stimulate the further development of these technologies, to achieve cost efficiencies in mass production, to promote the development of complementary technologies and skills and to stimulate changes in social organization that are important to the wider diffusion of the new technology;
- to build a constituency behind a product—of firms, researchers, public authorities—whose semi-coordinated actions are necessary to bring about a substantial shift in interconnected technologies and practices.[35]

How does one create technological niches and manage them? First of all, it must be noted that niches are platforms for interaction; they emerge out of a process of interaction shaped by many actors. They cannot be controlled. Still, governments could try to contribute to these processes of niche formation by setting up a set of successive experiments with a number of new technologies; this is strategic niche management.[36] Such a policy consists of five steps (elements): the choice of technology, the selection of an experiment, the set-up of the experiment, scaling up the experiment and the breakdown of protection by means of policy. We now describe the elements, and the problems and dilemmas involved.

The Choice of Technology

There are usually different types of solutions for a problem, with different costs and benefits. A choice must be made as to which technology will be supported. Technologies appropriate for support through strategic niche management are technologies that are outside the existing regime or paradigm, but may greatly alleviate a social problem (like environmental degradation or road congestion) at a cost that is not prohibitively high. To be able to do so, the technology must meet four additional criteria, apart from the social precondition. The new technology must:

- have major technological opportunities embedded in it, have sufficient scope for branching and extension and for overcoming initial limitations—this is the technological-scientific precondition;
- exhibit temporal increasing returns or learning economies—the economic precondition;
- be consistent with actual or feasible forms of organization and control and be compatible with important user needs and values—the managerial and institutional precondition;
- be already attractive to use for certain applications in which the disadvantages of the new technology count less and the advantages are highly valued.

The first four preconditions—the social, technological-scientific, economic and managerial (or institution) preconditions—are preconditions for regime shifts, identified by Smith in the project 'Technological paradigms and transitions paths'. The fifth precondition is an additional precondition for the management of regime shifts through the creation and development of niches.

This step also shows a dilemma for strategic niche management. Strategic niche management is aimed at exploring options for co-evolution of technologies and its contexts. Creating path dependencies too early by focusing on a specific technology may lead to a mismatch between emerging application conditions and the chosen new technology. Strategic niche management as a transition tool rather than a market introduction strategy will have to allow for a variety of technological options and explorations of these options, while simultaneously working towards the embedding of these options.

The Selection of an Experiment

After choosing a technology eligible for support, we need to choose an appropriate setting in which the new technology is to be used. This should be a setting or space in which the advantages of the technology are valued highly (because of specific problems like local pollution) and the disadvantages (in terms of costs of discomfort) count less. The space may be a certain application (for example, the use of solar cells for pleasure boats), a geographical area (a region or a city) or a jurisdictional unit. The heterogeneity of the selection environment means that there are almost always areas and types of application for which the new technology is attractive, in which the disadvantages count less and the advantages are valued higher. Electric vehicles that do not emit pollutants at the point of use are attractive for use in cities with high levels of pollution. The disadvantages of electric vehicles, such as their low range and the need to recharge the batteries in charging stations, are less problematic for fleet owners (taxi companies, utilities, public transport companies) than for consumers. Consequently, the use of electric vehicles by fleet owners in cities qualifies as a societal experiment.

The Set-up of the Experiment

This is perhaps the most difficult step, because a balance must be struck between protection and selection pressure. Finding a balance between protection and selection pressure is a continuing task for niche managers. Protection should be not too generous: technology developers must be forced to take care of user requirements and impelled to eliminate negative side-effects connected with the wide-scale application of a new technology. On the other hand, the selection pressures should not be too strong, putting development work under time pressures and making companies opt for conventional solutions that offer short-term benefits at the expense of long-term benefits. Too much protection may in the end lead to expensive failures, and too little protection may forestall different paths of development.

The choice of niche policies needs to be based on the barriers to the use and diffusion of the new technology. These barriers may be economic, when the new technology is unable to compete with conventional technologies, given the prevailing cost structure. They may be technical, such as the lack of complementary technologies, needed new infrastructure or appropriate skills. And they may be social and institutional barriers, such as existing laws, practices, perceptions, norms or habits. An integrated and coordinated policy is required to deal successfully with these barriers. Possible elements of such a policy are the formulation of long-term goals, the creation of an actor network, coordination of actions and strategies and, where needed, the use of taxes, subsidies, public procurement and standards.

Scaling up the Experiment

The next step concerns scaling up the experiment by means of policy. Even a highly successful experiment may require some kind of support from public policy-makers in the form of preferential treatment *vis-à-vis* less environmentally benign technologies. Again, this raises the question of how far governments should go in support of a particular technology, such as whether they should bear the costs or let others carry part of the costs.

The Breakdown of Protection

The final step is the phased breakdown of protection. Support for the new technology may no longer be necessary or desirable when the results are disappointing and prospects are dim.

Who Should Do Strategic Niche Management?

Having described the steps of strategic niche management, we turn to the important issue of who should do strategic niche management: a government agency, private company or (policy) entrepreneur. In practice, different actors may be the niche manager: state policy-makers, a regulatory agency, local authorities (e.g. a development agency), non-governmental organizations (NGOs), a citizen group, a private company, an industry organization, a special interest group or an independent individual, depending on who is best qualified to take on this task, which will differ from case to case. It should be noted, however, that just like normal management, niche management is not the purview of a single actor but a collective endeavour. Niche management policies are the collective (negotiated) outcome of different interactions at different levels. Some actors, however, are likely to take on a more dominant role as niche managers than others, and may therefore be called 'niche managers'. The niche manager may be a person or an organization (for example, many projects have a so-called 'project bureau' that is formally in charge of the project management).

We wish to emphasize that strategic niche management is not just something for governments: industry and NGOs are well placed to initiate and run niche projects. As a rule, government should take on those roles that it can do better than others; it should not take on the responsibility for running the experiment, as this is probably best done by professionals with their own social networks. As noted, governments have a special role as a enabler or facilitator to make sure that something happens, and that the project yields satisfactory results (which requires monitoring, evaluation of outcomes and policies and, in the case of undesirable outcomes, the judicious exertion of pressure and the correction of adverse actions and policies). As to the role of different levels of government, local governments are best placed to engage in local affairs such as network management. Regional and state governments may act as co-sponsor for projects that may be used on a larger scale. They could also help in the upscaling of successful experiments, through sponsorship or macro-policies (like changes in the regulatory framework and the use of fiscal incentives). National and regional governments also have a special responsibility for making sure that there is a broad social learning process. This could be done by supporting a portfolio of niche projects, instituting technology appraisals and social discourses (in which the technologies are evaluated along a wide range of dimensions) and disseminating the knowledge that is gathered in the projects.

As a related point, the niche manager need not be the same person or organization during the niche management process; as the process moves along, there may be a need for a different niche manager.

With respect to the steps of strategic niche management, we wish to assert a warning: strategic niche management is more than the execution of the above five steps. If the execution of the steps was done too mechanically, the reflexive side of strategic niche management and its primary aims would be degraded. The primary aims of strategic niche management are stimulating learning about problems, needs and possibilities of a technology, building actor networks, alignment of different interest to a goal, altering the expectations of different actors and fostering institutional adaptation; the steps are just a way to achieve this. To elaborate on the primary aims of strategic niche management, we discuss three key processes in niche formation. Experiments set up as part of a strategic niche management policy must contribute to these processes in the various steps discussed.[37]

Processes Constituting Niche Formation

Coupling of Expectations

In the early years of development, the advantages of a new technology are often not evident. Their value still has to be proven, and there are many resisting forces. In order to map the new technology, the interested actors therefore make promises and raise expectations about new technologies. Promises of a new technology are an important element in niche development, and must, therefore, be taken up in strategic niche management procedures. Promises are especially powerful if they are shared, credible (supported by facts and tests), specific (with respect to technological, economic and social aspects) and coupled to certain societal problems which the existing technology is generally not expected to be able to solve. To couple expectations about technologies to societal problems, actors will translate their own expectations to other actors and engage in cooperation.[38] Furthermore, activities will be developed to substantiate the expectations; for example, by conducting research or by employing experts. When sufficient support has been gained and the niche has been formed, close attention has to be paid to the development of expectations. Niche formation and the development of a 'market of expectations' go together.

Articulation Processes[39]

We have pointed out that there are a number of barriers to the introduction and use of a new technology. It is important to learn more about these barriers and how they may be overcome. Many of the barriers involve uncertainty and perceptions. Learning—about needs, problems and possibilities—should thus be an important aim of niche management policies. Design specifications, user requirements and side-effects need to be articulated. The following articulation processes are particularly important:

(1) Articulation of technical aspects and design specifications. Which adjustments to the technology are required? What is the scope for learning, and for overcoming initial limitations?
(2) Articulation of government policy. What changes in the institutional structure and legislation are necessary to make an application of the technology possible or to stimulate its use? Should the government assume a different role?
(3) Articulation of cultural and psychological meaning. Which symbolic meaning can be given to the new technology? For example, can it be labelled and promoted as a safe and environmentally benign technology, as a 'feminine technology' and/or as a technology that fits a modern life-style?
(4) Articulation of the market: for whom (which users) is the new technology produced and what are the consumers' needs and requirements? How can the technology be marketed in an economically sound manner?
(5) Articulation of the production network: who should produce and market the new technology and fuel?
(6) Articulation of the infrastructure and the maintenance network: which complementary technologies, capabilities and infrastructure must be developed? Who looks after the maintenance of the new technology? Who is responsible for recycling or waste?
(7) Articulation of societal and environmental effects: what effects does the new technology have on society and the environment?

Experiments are a way to stimulate articulation processes that are necessary for the new technology to become socially embedded. An important aim of experiments should therefore be to stimulate the articulation of needs, problems and possibilities and to enact a broad learning process. For example, an experiment with electric vehicles in the Netherlands in the early 1990s resulted in a much clearer picture of the potential of electric vehicles. It featured a series of articulation processes: articulation of technical problems (malfunctioning of batteries in particular), articulation of user requirements and experiences (a clearer picture of for whom the technology would be attractive—fleet owners such as taxi companies, delivery firms), indications that technological limitations could be overcome (through changed driving behaviour and planning of trips, identification of regulatory constraints)[40] and, finally, suggestions as to how Dutch industry could benefit from the electric vehicle market.[41]

Network Formation

The development of a niche may also require the formation of a new actor network. Actors with vested interests in other technologies will generally not be interested in stimulating a new, competing technology. They may participate in the developments for defensive reasons but will show no real initiative. There are many examples of actors trying to slow down or even stop the niche from developing. In order to expand the niche, specific new actors must therefore often be involved in the affair, and the activities of the existing actors and their interactions ought to be changed. New network relations should be developed in which the new technology can function as desired. Public authorities could help to create such networks. They may also help to create and articulate a vision of where the sector or society should be heading. This would help to coordinate the strategies of technology developers, investors, regulators and users. In order to have a major impact, these visions must be accompanied by policy measures, such as the announcement of future regulations or taxes with respect to emissions and the setting of clear policy goals.

Care should be taken, however, that the development of the technology is not dominated by industry, but that the users and 'third parties' can also contribute their ideas. Among these third parties are the actors who are affected by the results of the technology, or organizations such as citizen groups and environmental groups.

Final Remarks

The niche policies should consist of a package of measures that deal with the different barriers in combination. The barriers should not be considered individually, lest we lose sight of the coherence and interaction between the different factors. Policies should also be aimed not just at changing the structure of incentives and constraints but far more at learning and coordination. Possible ways to do this are by bringing together different parties (firms, universities, research institutes) to work on a problem, providing financial assistance, and manipulating technological and economic expectations—for example, by securing a (future) market for a new product. In the case of technological controversies, they could arrange discussions between proponents and opponents to generate better understanding of the issues, and by doing so guide technology developers in their decisions. As noted, learning and institutional adaptation should be an important focus of policies. This will require a new role for public policy-makers, that of an enabling actor and catalyst rather than a regulator or technology sponsor. This new type of policy may be called a socio-technical alignment policy.[42] Within this perspective, the challenge of governments is not to maximize some imaginary welfare function but to ensure that the processes of co-evolution of technological supply and demand lead to desirable outcomes, in both the short term and the long run. This is also the approach of constructive technology assessment.[43]

In our view, strategic niche management is not just a useful addition to a spectrum of policy instruments: given the difficulties and disadvantages of other strategies, it may be the only feasible way to transform environmentally unsustainable regimes, even though strategic niche management in itself will not be likely to be sufficient to achieve a regime shift. To achieve a regime shift away from unsustainable practices, additional policies are needed, such as changes in the regulatory framework and state tax policies. Strategic niche management may help to pave the way for making such changes in state policies, by showing a possible solution to a problem. Thus, strategic niche management is more likely to act as a stepping stone, which facilitates—rather than forges—change in a new direction. But there are also problems with it, and these need to be pointed out. First, one must find a balance between protection and selection pressure. Too much protection may lead to expensive failures and too little protection may preclude or forestall different paths of development. This calls for on-going monitoring and evaluation of co-evolution processes and of the support policies themselves.

Second, there is no guarantee for success: changing circumstances may render the technology less attractive and technological promises may not materialize. Hence, it is important to promote technologies with ample opportunities for improvement, with a large cost-reduction potential that can be applied in a wide range of applications. Even if the technology does not yield short-term benefits, it may well be a useful technology in the longer term. This means that it is important to take a long-term perspective. For example, government support of electric vehicles has been criticized on the grounds that the environmental gains are limited and their performance is poor compared to internal combustion vehicles.[44] But this need not be true in a long-term vision, where electricity is generated by solar energy and advanced batteries become available. Improved batteries may also pave the way for hydrogen fuel-cell powered automobiles and wider use of solar energy.

Third, it may be difficult for governments to end the support for a technology because of the investments that have been made and resistance from those who have benefited from such programmes: the 'angry technological orphans' (as Paul David has called them) whose expectations have been falsely nourished.[45]

Fourth, it is important to create critical mass (sufficient momentum). To date, most experiments with alternative transport technologies have been rather small and have covered a short period of time. Experiments should be of sufficient size to allow for learning economies and to bring about institutional change. There is also a danger that the knowledge that is accumulated in the experiment is lost once the experiment is over.

Notes and References

1. For comments and suggestions, we would like to thank Boelie Elzen, Arie Rip, two reviewers and all project partners involved in the EU-SEER support project on strategic niche management.
2. Such systems consist of a fleet of vehicles that can be rented for short periods, and central management that controls their location and disposition. Examples are the Praxitèle and TULIP systems currently experimented with in France.
3. See, for example, A. Irwin & P. Hooper, 'Clean Technology, Successful Innovation and the Greening of Industry', *Business Strategy and the Environment*, *1*, 1992, pp. 1–11; and K. Green & I. Miles, 'A Clean Break? From Corporate Research and Development to Sustainable Technological Regimes', in: R. Welford & R. Starkey (Eds), *Business and the Environment* (London, Earthscan Publications 1996), pp. 129–144.
4. A. H. van de Ven, 'Central Problems in the Management of Innovation', *Management Science*, *32*, 1986, pp. 590–607.
5. See M. Hard & A. Knie, 'The Ruler of the Game: the Defining Power of the Standard Automobile', in: K. H. Sorensen (Eds), *The Past, Present and Future of the Motorcar in Europe* (Luxembourg, European Commission, 1994), pp. 137–158.
6. See W. J. Abernathy & J. M. Utterback, 'Patterns of Industrial Innovation', *Technology Review*, *50*, 1978, pp. 41–47. See also J. M. Utterback, *Mastering the Dynamics of Innovation* (Boston, Harvard Business School Press, 1994).
7. See G. Dosi, 'Technological Paradigms and Technological Trajectories: A Suggested Interpretation of the Determinants and Directions of Technical Change', *Research Policy*, *6*, 1982, pp. 147–162; G. Dosi, 'The Nature of the Innovation Process', in G. Dosi, C. Freeman, R. Nelson, G. Silverberg & L. Soete (Eds), *Technical Change and Economic Theory* (London, Pinter Publishers, 1988), pp. 221–238. R. R. Nelson & S. G. Winter, 'In Search of Useful Theory of Innovation', *Research Policy*,

6, 1977, pp. 36–76; R. R. Nelson & S. G. Winter, *An Evolutionary Theory of Economic Change* (Cambridge, MA, Bellknap Press, 1982).

8. Dosi, 1982, *op. cit.*, Ref. 7, p. 153.
9. Nelson and Winter, 1977, *op. cit.*, Ref. 7, p. 57.
10. G. Dosi, 'Sources, Procedures and Microeconomic Effects of Innovation', *Journal of Economic Literature, 26*, 1988, pp. 1120–1171.
11. For this reason, Rip and Schot have been advancing quasi-evolutionary theories based on a conceptualization of the interaction between selection environment and the variation process. In their conceptualization, variation and selection are neither independent nor coincidental processes. Selection may be anticipated, temporarily excluded or attenuated in the variation process (through processes of niche formation). In addition, institutional links exist between variation and selection, the so-called technological nexus. A. Rip, 'A Quasi-evolutionary Model of Technological Development and a Cognitive Approach to Technology Policy', *Rivista di Studi Epistemologici e Sociali Sulla Scienza e la Tecnologia, 2*, 1992, pp. 69–103; J. Schot, 'The Policy-relevance of the Quasi-evolutionary Model: The Case of Stimulating Clean Technologies', in: R. Coombs, P. Saviotti & V. Walsh (Eds), *Technological Change and Company Strategies* (London, Harcourt Brace Jovanovich, 1992), pp. 185–200; J. Schot, 'The Usefulness of Evolutionary Models for Explaining Innovation. The Case of The Netherlands in the Nineteenth Century', *History, and Technology*, forthcoming.
12. The discussion of these barriers and included empirical examples are taken from B. Elzen, R. Hoogma & J. Schot. *Mobiliteit met Toekomst. Naar een Vraaggericht Technologiebeleid*, Report for the Dutch Ministry of Traffic and Transport (The Hague, Ministerie van Verkeer en Waterstaat, 1996). The report will be available in English through a commercial publisher in 1998. For similar accounts of barriers, we refer to E. Tengström, *Why Have the Political Decision-makers Failed to Solve the Problem of Car Traffic?* (Gothenberg, University of Gothenberg, Reports in Human Technology no. 2, 1994), and Hard and Knie, *op. cit.*, Ref. 5.
13. Elzen *et al.*, *op. cit.*, Ref. 12.
14. The ZEV legislation may be changed to include hybrid-electric vehicles, to be defined as 'equivalent zero emissions vehicles'.
15. For this notion, see R. Kemp & L. Soete, 'The Greening of Technological Progress: An Evolutionary Perspective', *Futures, 24*, 1992, pp. 437–457.
16. Since an exhaust gas catalyst does not function well at low temperatures, pre-heating the catalyst markedly reduces the level of harmful emissions. The catalyst can be pre-heated with electricity from the grid or with a device that stores engine heat and releases it when the engine is started. Petrol cars can be equipped with a pre-heated catalyst without further changes to the vehicle. Alternative, cold-start emissions may be stored and treated when the catalyst is warmed up.
17. J. F. Porac, J. A. Rosa & M. S. Saxon, 'America's Family Vehicle: The Minivan Market as an Enacted Conceptual System', Paper for the Multidisciplinary International Workshop on Path Creation and Dependence, Copenhagen Business School, August 1997.
18. The typical range of a current generation electric vehicle is 100 km, the top speed 90 km/h, and charging takes some 6 hours. Refuelling a natural gas vehicle also takes longer than refuelling a conventional car. On the other hand, hybrid-electric cars have none of these disadvantages. Their market introduction could thus be as successful as that of the minivans. Even the cost aspect is comparable: minivans are substantially more expensive than conventional cars and so are hybrids expected to be.
19. Dosi, *op. cit.*, Ref. 7; Nelson & Winter *op. cit.*, Ref. 7.
20. Nelson & Winter, *ibid.*, p. 57.
21. The selection environment is also shaped by the experience of users and the adjustment of users (both companies and consumers) to particular technologies. For a discussion of co-evolution of technology and society, see A. Rip & R. Kemp, 'Technological Change', in: S. Rayner & E. L. Malone (Eds), *Human Choice and Climate Change, Volume II, Resources and Technology* (Washington DC, Batelle Press, 1998); and A. H. Molina, 'In Search of Insights into the Generation of Techno-economic Trends: Micro- and Macro-constituencies in the Microprocessor Industry', *Research Policy, 22*, 1993, pp. 479–506. Molina does not refer to the concept of co-evolution, but argues in similar way (pp. 483): "Sociotechnical constituencies may be defined as dynamic ensembles of technical

constituents (tools, machines, etc.) and social constituents (people and their values, interest groups, etc.), which interact and shape each other in the course the creation, production and diffusion of specific technologies. Thus the term 'sociotechnical consituencies' emphasises the idea of interrelatedment. It makes it possible to think of technical constituents and social constituents stressing the point that in the technological process both kind of constituents merge into each other." Finally, we refer to R. Garud & M. A. Rappa, 'A Socio-cognitive Model of Technological Evolution: The Case of Cochlear Implants', *Organization Science*, *5*, 1994, pp. 344–362.

22. In Rip and Kemp, *op. cit.*, Ref. 21, the structured nature of a technological regime is accentuated by defining a technological regime as the coherent complex of scientific knowledges, engineering practices, production process technologies, product characteristics, skills and procedures, and institutions and infrastructures that are labelled in terms of a certain technology (for example, a computer), mode of work organization (for example, the Fordist system of mass production) or key input (like steel or hydrocarbons). Since the accommodation between the elements in the complex in never perfect, it is perhaps better to talk about a semi-coherent complex. For similar definitions see R. Kemp, 'Technology and the Transition to Environmental Sustainability. The Problem of Technological Regime Shifts', *Futures*, *26*, 1994, pp. 1023–1046; R. Kemp, *Environmental Policy and Technical Change. A Comparison of the Technological Impact of Policy Instruments* (Cheltenham, Edward Elgar, 1997).
23. Large technical systems as defined by Thomas Hughes can be seen as a special kind of regime, one in which material connections and the building up of an infrastructure are crucial to its diffusion. This creates special effects (the importance of load management), and leads to what Hughes has called momentum. T. P. Hughes, *Networks of Power. Electrification in Western Society 1880–1930* (Baltimore, Johns Hopkins University Press, 1983).
24. It is important to note that a technological regime does not fix technological choices, but is open to various kinds of change—at the level of regime components and even the overall architecture. Technological regimes change in conjunction with the evolution of social needs, technological possibilities and organizational change like new management systems.
25. See, Rosenberg 'The Direction of Technological Change: Inducement Mechanisms and Focussing Devices', in his book *Perspectives on Technology* (Cambridge, Cambridge University Press, 1976), pp. 108–125; and Fransman, *The Market and Beyond. Cooperation and Competition in Information Technology in the Japanese System* (Cambridge, Cambridge University Press, 1990).
26. R. Kemp, I. Miles, K. Smith *et al.*, Technology and the Transition to Environmental Stability. Continuity and Change in Complex Technology Systems, final report of the project 'Technological Paradigms and Transition Paths: The Case of Energy Technologies' for the SEER research programme of the Commission of the European Communities (DG-XII), 1994.
27. When steamships entered the market, sailing ship manufacturers stepped up their efforts to improve sailing ships in order to protect their business. This resulted in great improvements which helped sailing ships to survive the competition for a certain while.
28. See also A. Rip, 'Introduction of New Technology: Making Use of Recent Insights from Sociology and Economics of Technology', *Technology Analysis & Strategic Management*, *7*, 1995, pp. 417–431.
29. Hughes, *op. cit.*, Ref. 23.
30. For these and other examples see Schot, forthcoming, *op. cit.*, Ref. 11.
31. The use of process management as a means of social-political governance has been advocated by various policy scientists. See, for instance, J. Kooiman (Ed.), *Modern Governance. New Government–Society Interactions* (London, Sage, 1993); P. Glasbergen (Ed.), *Managing Environmental Disputes. Network Management as an Alternative* (Dordrecht, Kluwer, 1994).
32. J. W. Schot, B. Elzen & R. Hoogma, 'Strategies for Shifting Technological Systems. The Case of the Automobile System', *Futures*, *26*, 1994, pp. 1060–1076; and J. Schot & A. Rip, 'The Past and Future of Constructive Technology Assessment', *Technological Forecasting and Social Change*, 1997, pp. 251–268.
33. This definition is based on J. Schot, A. Slob & R. Hoogma, *Implementatie van Duurzame Technologie als een Strategisch Niche Management Probleem* (Den Haag, Programma Duurzame Technologische Ontwikkeling, 1994), Werkdocument CST3. The concept of strategic niche management is under development in the EU funded project 'Strategic Niche Management as a Tool for Transition to

a Sustainable Transport System'. For more information, contact the authors or visit the website: http://www.jrc.es/strategic niche management/.

34. We specifically include the adjective 'strategic' in the label of the approach, to stress the importance of anticipation. In running an experiment, the actors should adopt a forward-looking perspective, by anticipating emerging opportunities and possible threats that create, widen or close windows of opportunity.
35. See also K. Green, 'Creating Demand for Biotechnology: Shaping Technologies and Markets', in: Coombs *et al.*, *op. cit.*, Ref. 11, pp. 164–184.
36. See also M. Teubal, 'A Catalytic Evolutionary Approach to Horizontal Technology Policies', *Research Policy*, *25*, 1997, pp. 1161–1188. Teubal calls for technology policy as a succession of experiments (p. 1165).
37. Based on J. Schot *et al.*, *op. cit.*, Ref. 33.
38. For a discussion of technological expectations, see A. Rip, 'A Quasi-evolutionary Model of Technological Development and a Cognitive Approach to Technology Policy', *Rivista di Studi Epistemoligici e Sociali Sulla Scienza e la Technologia*, *2*, 1992, pp. 69–103; and H. van Lente, 'Promising Technology. The Dynamics of Expectations in Technological Developments', PhD thesis, Enschede, University of Twente, 1993.
39. For the notion of articulation process we refer to K. B. B. Clark, 'The Interaction of Design Hierarchies and Market Concepts in Technological Evolution', *Research Policy*, *14*, 1985, pp. 235–251.
40. Under the Dutch road tax system, electric vehicles fall in the heavily taxed 'rest' category; moreover, road vehicles are taxed according to their weight, which puts electric vehicles, with their heavy batteries, at a disadvantage. To take care of this problem, the Dutch government announced that it would give a tax break and investment subsidy to electric vehicles. A similar policy exists in the UK where electric vehicles are exempted from excise taxes.
41. See Schot *et al.*, 1994, *op. cit.*, Ref. 32.
42. See Rip & Kemp, *op. cit.*, Ref. 21; Molina, *op. cit.*, Ref. 21.
43. See A. Rip, Th. J. Misa & J. Schot, *Managing Technology in Society. The Approach of Constructive Technology Assessment* (London, Pinter Publishers, 1995).
44. See, for example, D. Wallace, *Environmental Policy and Industrial Innovation. Strategies in Europe, US and Japan* (London, Earthscan Publishers, 1995).
45. P. A. David, 'Path-dependence in Economic Processes: Implications for Policy Analysis in Dynamical System Contexts', CEPR discussion paper, Stanford, 1992.