STRATEGIES FOR SHIFTING TECHNOLOGICAL SYSTEMS

The case of the automobile system

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 Californian and Dutch efforts to produce electric vehicles are explored and compared. Three strategies are put forward that could turn electric vehicles from an elusive legend, a plaything, into a marketable product: technology forcing creating a market of early promises, experiments geared towards niche development and upscaling (strategic niche management), and the creation of new alliances (technological nexus) which bring technology, the market, regulation and many other factors together. These strategies deployed in the Californian and Dutch context are analysed in detail to explore their relative strengths and weaknesses and to argue in the end that a combined use of all three will increase the chances that the dominant technological system will change. The successful workings of these strategies crucially depend on the coupling of the variation and selection processes, building blocks for any evolutionary theory of technical change. Evolutionary theory lacks understanding of these coupling processes. Building on recent insights from the sociology of technology, the authors propose a quasi-evolutionary model which underpins the analysis of suggested strategies.

The automobile is highly entrenched in our society and has shaped it deeply. In 1987 126 000 cars rolled off the assembly lines each working day, and some 400 million vehicles invade the world’s streets today.1 These cars are not just artefacts, but

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represent a technological system where they are tied together with roads, gas stations, oil companies, automobile retailers, repair shops, and car drivers, to name just a few elements. In Western societies a longstanding love affair with the automobile has developed, which has proved to be contagious. Also in non-Western countries most people who can afford a car are eager to own one. The phrase The Automobile Age, used as a book title by the American historian James Flink, aptly describes the place of the artefact in our world. Since the end of the 1960s, however, the car has lost its innocence. The automobile has been criticized for causing many persistent problems. Dependence on oil from the Middle East, unsafe cities, environmental degradation and traffic jams, to name the most important ones. Apparently, these problems have not affected car sales. The viability of the automobile system has hardly diminished.

In evolutionary theories of technical change automobile history is often portrayed as an exemplar of lock-in. In 1895 the gasoline powered car was held to be the least promising option. Steam and electric vehicles contained attractive futures. Due to a series of circumstances gasoline got the lead and subsequently proved to be unassailable, so the story goes. René Kemp has summarized factors that make existing technological systems, including the automobile system, so hard to change. Prevailing systems have gone through a series of incremental improvements and have gained precise user understanding. To solve compatibility problems a number of complementary technologies have been developed. Misfits with the societal and political system have been accommodated.

The question then arises, how can radical new technologies ever emerge, since they will always be confronted with a broad range of barriers—technologically and economically superior competitors and a hostile selection-environment? Research shows that it is impossible to isolate any single factor, and that accidental causation has a role to play as well. Perhaps there is nothing special about the fact that new technologies emerge. The variety and richness of potential alternatives are astonishing. In the automobile case, hydrogen, natural gas and various bio-fuels compete with gasoline, and electric motors provide another propulsion system. The question then becomes, how do new technologies compete and gain momentum or how do they get selected? How are they protected against the myopia of the existing technological system?

One possibility is that the existing system loses viability because the selection environment is changing and provides new types of challenge which cannot be met with the dominant technology, or require advances which are only possible at too much marginal cost. This is certainly not true for the automobile. Industry perceives many new promising technological options within the dominant paradigm of the internal combustion engine which will reduce many problems substantially. For example, experts assess that existing engines could run about 40% more economically. Another possibility is that new technologies use a niche that protects them against too harsh selection and provides space to grow. Laboratories provide such a space, but technologies need to survive in the market place. Sometimes the existing market geography provides niches too. Automobiles were first used by the aristocracy (in Germany and France) who were eager to develop an alternative to mass transport which had broken their hegemony on the road, based on horse carriages. Many disadvantages were taken for granted: driving automobiles was dangerous, uncomfortable, unreliable and noisy. Their advantages, notably their ability to climb all hills and drive long distances, made them attractive for physicians who had to visit patients living in remote places. This provided yet another niche.
market. Adoption by US farmers, who were seeking ways to overcome their relative isolation, turned the automobile into a mass product. In this article we explore strategies for shifting technological systems, using the automobile as a case. We focus on the question of how to get the electric vehicle on to the road in sufficient numbers. Although the developed insights and strategies can be taken up by firms, pressure groups and others, we take a government perspective. Our starting point is the taxonomy of strategies developed by Schot (but see Rip and Van den Belt as well). On the basis of a quasi-evolutionary model of technical change Schot distinguishes three strategies:

(1) Development of alternative variations. Governments could try to stimulate technologies which are not developed in the market place. Examples are wind and solar power energy technologies. If not handled carefully, such protected variations cannot survive in the real selection environment. Thus, a gradual introduction of a new option is necessary. Following Rip, we label this strategy strategic niche management. In this article we explore experiments as a way to shape strategic niche management.

(2) Modification of the selection environment through regulation and other instruments. We explore the viability of strict regulation with the intention to force industry to develop new technologies and bring them to the market. Stringent regulation is important for the creation of new expectations about viable technological futures.

(3) Creation or utilization of institutional links, called the technological nexus, between places that produce variations and their selection environments. Such a nexus helps translate selection pressure into criteria and specifications used in the design process. Schot has explored examples such as marketing, environmental and quality departments within firms. We explore whether and how new networks which develop around new technological options could effectively serve a nexus function.

Our aim is to elaborate these strategies and gain more insight into their relative strengths and weaknesses. We argue that a combined use of all three will increase the chances that the dominant technological system will change.

All three strategies are being tried out for electric vehicles. In the USA the Californian state government has developed a technology forcing programme. This has led to a number of other initiatives, including experiments with electric vehicles and the formation of new actors and networks. In Europe the experimental route has been developed in the Netherlands, Germany, France and Sweden. Through a process geared towards niche development and upscaling, participants in these experiments hope to develop a new market. In this article we draw only on empirical material from the Dutch case.

In order to prepare and deepen the presentations of our empirical material, we first present the theoretical background of our argument. We argue that simple evolutionary models are necessarily incomplete because variation and selection processes, the building blocks of any evolutionary model, are envisaged as independent instead of being coupled. To emphasize the intentional and strategic character of this coupling process we prefer to speak of quasi-evolution. Focusing on the coupling process is the key to assessing the prospects of existing policies and to identifying ways of coming up with advice on how to upgrade these policies. Moreover, it allows us to overcome the mechanical and deterministic overtones of evolutionary economics noted by Green et al.
Quasi-evolution and strategies for change

A common weakness of the evolutionary approach is its neglect of crucial intermediary processes occurring between variation and selection. Insights developed in the recent sociology of technical change can help to remedy this flaw. It is not our intention to summarize evolutionary and sociological theories at length. That is satisfactorily done elsewhere. We focus on clarification of the coupling between variation and selection.

Evolutionary theory starts by creating a split between variation processes (in which technologies develop) and selection processes. The variation process is a search process characterized by trial and error, and uncertainty. Various technical options are developed, but not every conceivable variation is part of the development process. Restricting the number of variations that are tried out emerges from what Dosi calls a technological ‘paradigm’. This concept is defined as a set of rules or heuristics that indicate what the relevant problems are and in which direction the solution should be sought. The effect of the paradigm is, therefore, that the search process is driven in a certain direction and does not take up directions that do not fit within the paradigm. Selection between the technical options generated during variation takes place in two ways. Ex post selection occurs when the variations (generated options) are exposed to the selection of a market. The ensuing process, with some options succeeding while others are eliminated, can be described by the Darwinian concept of survival of the fittest. The variation is stochastic (or blind), and like orthodox Darwinian selection the generation of variants takes place independently of their subsequent selection. The second form of selection, ex ante, occurs when influence from the selection environment is exerted on the generation of variations. Ex ante selection resembles a Lamarckian process, where an organism generates variations that are favoured by its environment (in contrast to random mutations generating variations blindly). For firms and other variation generators this form of selection takes place when they anticipate possible selection pressures from the market or other sources. Nelson and Winter (and following their lead, other evolutionary economists) have replaced the narrow concept of the ‘market’ with the broader concept of the selection environment. The latter concept embraces not only the neo-classical market (structure and size of supply and demand as well as prices) but also all kinds of institutional factors (regulation, relationship between employers and employees, political structure) and even geographical factors. For their extended concept of selection environment, the same ex ante selection by anticipation occurs.

In contrast to evolutionary economists, constructivist sociologists deny the possibility of making a difference between variation and independent selection. For these analysts—including, as the central strands, actor network theory, system approach, and SCOT—content and form are given to technical developments simultaneously with the construction of their context. Each variation entails a script or scenario which, besides technical aspects, also includes social, political and environmental aspects. A classic example (again!) is the automobile. Callon described how engineers at Electricité de France (EDF) designed an electric car simultaneously with the whole environment in which such a car should function. For example, the engineers had to encompass in their planning not only the technical aspects but also government regulation, research programmes, and motor manufacturers’ production. This implies that engineers have to concern themselves not only with technology (batteries, fuel cells etc) but also with all kinds of economic
and political aspects, elements of the selection environment in evolutionary economics. Actors who develop technology are designated as heterogenous engineers in the actor network approach. They must realize both the technical side of their design, and also its social side. They must thus try to put a whole range of heterogenous elements in place in order to be able to realize their design. To put it another way, there is no independent variation and selection (the building blocks of the evolutionary model) but rather coevolution of both technology and the selection environment. Technologies appear as actor networks of heterogenous elements. The analysis must then focus on how links are made.

These insights developed within the sociology of technology enable us to criticize the way evolutionary economics tends to create a split, and conceptualize interaction between variation and selection processes. First, we notice that descriptions and analysis of variations only consist of technical details. Evolutionary economists do not acknowledge the heterogenous character of technology which is so central to sociological analysis. Second, they do not elucidate how variation interacts with the selection environment. They ignore how variations themselves change their selection environment, as is visible in all actor-centred analyses by sociologists, who portray restless actors bending the world to their will. Finally, their conceptualization of the influence of the selection environment on the variation process lacks a necessary sociological dimension. It does not become clear how this process actually works. Dosi has developed the notion of ex ante selection, which involves the redirection of heuristics, but fails to clarify how firms anticipate selection pressures, through what kind of dynamics.

To capture the valuable insights of both evolutionary and sociological accounts of technical change and simultaneously give substance to a perspective which analyses the coupling and decoupling processes that occur, we prefer a quasi-evolutionary model. The key feature of this model is its focus on the way variation and selection processes are partly independent and yet coupled. The starting point for a quasi-evolutionary model is the search processes which are embedded in heuristics. These search processes and the variations pursued are heterogenous by their very nature. The products of the search processes encounter selection environments, which have their own dynamics which are only partly determined by the variation process. Actors do try to anticipate and influence the selection environment. Until now three major coupling mechanisms have been identified: (1) voicing and articulation of expectations; (2) shaping of the technological nexus, institutional carriers which act on the variation and selection process simultaneously; (3) creation of niches in which new variations are exposed to selection pressure in a controlled way and thus protected against too harsh selection. The occurrence of these coupling mechanisms parallels the taxonomy of strategies provided above. As we noted for the strategies, they may occur together.

The Californian initiative

The situation in California offers a good example of the combination of strategies and mechanisms, and allows us to speculate about effects. The single most important stimulus for increased interest in electric vehicles (EVs) was the ambitious clean air standards set in California in 1988. Among a variety of other measures the California Air Resources Board (CARB) attempts to force manufacturers to develop cleaner cars. These attempts consist of the establishment of four progressively more stringent categories of vehicles: transitional low-emission vehicles (or TLEVs), low-emission
vehicles (or LEVs), ultra-low-emission vehicles (or ULEVs) and zero-emission vehicles (or ZEVs). Manufacturers may produce any combination of the first three groups as long as they meet increasingly stringent fleet average emission requirements each year. The proportion of ZEVs is prescribed as of 1998. In that year 2% of each manufacturer's passenger cars and light trucks must be ZEVs. This applies only to manufacturers who sell more than 35,000 vehicles per year in California, which is the case for most US and Japanese manufacturers. The percentage of ZEVs increases to 5% in 2001/2002, and 10% in 2003. In that year intermediate-sized manufacturers (mostly European) must also offer ZEVs. In 2003 it is expected that 400,000 ZEVs will be on the road. The Californian approach does not prescribe or advocate one specific solution. They only judge the environmental quality of each vehicle. It is for each manufacturer to decide which solution they will rely on. However, it is clear that only the electric vehicle will be able to meet the zero-emission requirement in 1998.

Much of the Californian interest in EVs stems from the failure to meet federal and state air-quality standards in many areas. Due to specific climatological and geological circumstances, combined with a high population density, the atmosphere in southern California is one of the most polluted in the world. For example, in Los Angeles the standards for ozone are exceeded on about half the days in the year. People suffer directly, which makes them prepared to support stringent state policies. In addition, California has built up a tradition of being first in enacting legislation that forces industry to curtail automobile emissions. Positive crankcase ventilation systems to reduce hydrocarbon discharge were required on all cars sold in California beginning with the 1963 model year. Exhaust control devices to reduce emissions of carbon monoxide, oxide of nitrogen, and lead compounds became mandatory in California beginning with the 1966 model year. It took Europe more than two decades to adopt similar measures. California hopes to reduce local emissions substantially through forcing EVs on the market. Even if emissions from power plants generating the electricity are considered, 'total chain' emissions in California are still substantially lower than from internal-combustion vehicles (ICVs). This is primarily due to the stringent emission control standards already in place for power plants. The result of these regulations is a strong bias towards natural gas use in power plants and away from coal or oil.

Economic interests are important too to understand the California initiative. California does not have a major domestic car industry that can disqualify the measures as unattainable or negative for the local economy. On the contrary the State of California sees the production of EVs and its components as an important future industrial activity for local military industry seeking civilian markets and local new innovative firms. New industries would profit from an enormous local car market, absorbing about 4% of world car production or up to 10% of the production of specific manufacturers. Its market is important in qualitative terms as well. Most automobile manufacturers believe that new trends are becoming visible first in California.

A bandwagon of initiatives

The California mandate has led to and is supported by a number of other local and national policy initiatives. In 1988 Los Angeles started an international competition for the sale of at least 5000 electric vans and 5000 electric passenger cars by 1995. This 'Los Angeles Initiative' resulted in a request for proposals which was distributed
worldwide. Three companies were selected from the 18 that responded. One (Clean Air Transport) is currently under contract to begin to design and manufacture the vehicle designated the LA301. In 1991 another initiative emerged. The City Council of Los Angeles formed a task force on Electric Vehicle Infrastructure. The purpose of this task force is to review all local opportunities to facilitate and encourage the use of EVs, and to recommend appropriate local laws and programmes. This has resulted in several actions to stimulate use of EVs. The following actions have been taken:

- building code requirements for new constructions to ensure that houses have adequate EV charging facilities;
- a requirement that the city provide EV charging facilities;
- a requirement that employers with more than 100 parking spaces provide preferential parking and/or charging facilities;
- incentives for airport-area hotels and car rental companies to use EVs as shuttle vans and a requirement that LA airport use EVs as a percentage of the airport fleet;
- a requirement that all park-and-ride lots have a percentage of spaces ready for EV use.

At the federal level a number of initiatives have been taken to support the Californian mandate. Under the Energy Policy Act of 1992 the federal government will give a 10% income tax credit on the price of an EV, up to a maximum of $4000. Under the same provision a tax credit up to $100,000 is provided for building refuelling stations. In addition $50 million is available for subsidies to vehicle demonstration projects and $40 million for infrastructure development. The Energy Policy Act also requires government fleets and fuel providers to start converting their fleets to alternative fuels beginning in 1996 or, in the case of electric vehicles, in 1998.

General Motors, Ford and Chrysler ('The Big Three') find the ZEV mandate problematic. They expect that the low performance of EVs combined with their high price will make it impossible to produce a product that can be sold in sufficient numbers to meet the 1998 2% mandate. They are asking for more time to develop better batteries. To push battery technology they participate in the US Advanced Battery Consortium (USABC), formally established in January 1991, that has targeted the development of a battery which will perform better and cost less than existing ones by the mid-1990s. Membership includes GM, Ford, Chrysler, the Electric Power Research Institute (EPRI) and some of its member utilities. In addition USABC and the US Department of Energy signed a Cooperative Agreement. The objective is to accelerate the EV market potential by advancing the most promising battery technologies. USABC has quantified mid-term and long-term objectives to be met by the end of 1994. The intent is to develop an advanced battery which meets the mid-term criteria, for which pilot prototype production can start in 1994, and to demonstrate the design feasibility of an advanced battery which meets the long-term criteria. The consortium will also help to achieve commonality of standards for certain aspects of batteries in order to make them more interchangeable. Next to batteries all three companies have developed prototypes for testing purposes. GM will build 50 Impacts (a purpose-built two-seater) which will be used by various customers. The tests started in spring 1994 and will last two years. Chrysler and Ford have taken a different approach. They have converted existing vehicles into electric ones.

For electric utilities transport is a new market that in their view needs to be developed. Creating an EV infrastructure is one of the primary concerns. They
invest in research projects on designing and prototyping charging facilities. Electric utilities challenge the perspective of the existing automobile industry who are looking for mass markets to sell thousands of vehicles. In their view electric vehicles will have to emerge out of smaller niches. An initial niche might be formed by users who would accept current state-of-the-art technology. The aim is to use the experiences of the initial users to improve the next series. The utilities see an important role for themselves in this process. They try to serve as an intermediate between vehicle development on the one hand and collecting practical experience on the other. Their initiatives include stimulating R&D in areas they feel are neglected, testing technologies, buying EVs for their own fleets and/or put them into the hands of users to gain experience. One of their undertakings is the so-called EV-5000 effort. This is a nationwide programme to put 5000 EVs on the road by 1996. To get more regular users interested, Californian utilities are considering providing financial incentives as well. They are discussing a rebate of $1500 to any EV purchaser. The money will come from the regular budget, and thus needs to be paid for by all customers. In addition they have proposed a lower electricity rate for EVs if the EV were to be charged off-peak.

In summary, the approach taken in California is a combination of technology forcing standards and facilitating initiatives taken by others, including funding of key technological developments and experiments. Explicitly, the authorities have chosen not to reduce mobility, for example through taxing gasoline or car ownership. They rely on new technological advances which is so much part of American culture. The initiatives discussed have defined a future space and market for a new technical artefact—the ZEV.

A speculative market of promises to be realized

Due to the Californian initiative the EV story has changed dramatically. It turned the EV from a toy and R&D project with no future, an elusive legend, into a marketable product. For decades the age of the electric car has been announced. In 1968 the US Society of Automotive Engineers published a feasibility study on a city car that would reduce emissions substantially. According to this study it would be possible to build small automobiles which produce negligible amounts of pollution. The proposed vehicle was a hybrid consisting of an electric engine and a small internal combustion engine. They expected that as a result of technological progress in the domain of batteries it would be possible to drive entirely on electricity within 10 years. The cost of the hybrid was expected to be comparable with the price of a Volkswagen. In 1973 Electricité de France (EDF) presented a plan for the introduction of electric vehicles. In 1979 General Motors presented an electrical version of its Chevette, and claimed that within 5–10 years commercial production would start. In 1990 10% of total production would consist of electric models. However, until now the electric car is not produced in large quantities, although research work continues.

What happened? First, pressure that came from the 1970s’ energy crisis faded away. This pressure was partly based on the expectation that shortage of oil would cause major problems and lead to a high gasoline price. This turned out not to be the case. Automobile sales grew to new heights and the use of the catalytic converter promised to solve many environmental problems. Second, it turned out to be impossible to overcome certain disadvantages of EVs compared to conventional cars, despite substantial R&D investment. Their acceleration is slower, their top speed is lower, and their range per charge is much shorter, typically between 70 km
and 140 km for city traffic. Technologically, the battery was identified as the most problematic component. Performance of electric vehicles is highly dependent on it. Batteries are also problematic because they are the largest single cost item, making electric vehicles very expensive when compared to ICVs. In the Netherlands, the electric version of the Peugeot J5, for instance, costs about $32,000 (including lead-acid battery and charging equipment) while the gasoline variant costs about $18,000. New types of batteries, such as sodium-sulphur batteries are even more expensive: the one Ford uses in its Ecostar model costs $46,000. This price could only come down if they were to be produced in large volume. Another related problem area is expected lifespan of batteries. Current lead-acid batteries have an average lifetime of 2–3 years. The lifetime of advanced batteries has yet to be established.

At the beginning of the mid-1980s the EV was removed from the R&D agenda of most firms and governments or considered to be a low priority. Some firms and governments were still working on it, mainly to preserve their knowledge base, and they hoped for spin-offs for regular automobile R&D. This has changed dramatically as a result of the California state legislation. The legislation defined a future market in California that is expected to open up in 1998. In the meantime, a speculative market of early promises and expectations about new developments has emerged. On this market new options are offered and selected. Firms develop R&D projects, partly to influence this market. A good illustration is the development of the Environmental Concept Car by Volvo through its design centre located in California. The Environmental Concept Car is a hybrid combining gas turbine and battery technology. This car is developed by Volvo ‘as a vehicle for discussion’. Volvo wants to push big family cars and to preclude a new future in which small electric city cars will dominate the market. In the advertisement material the rhetorical question is asked: ‘Could you accept a small battery-powered car just for short trips, for example, or will you still need a family car designed for efficiency, versatility and safety?’ Other automobile manufacturers have developed their prototypes as well, focusing mainly on battery performance. Although they claim that EVs will not be able to replace ICVs because their customers will not buy it, they feel forced to act on the market of early promises, put up their expectations and engage themselves in R&D projects. The electric utilities argue the other way round. They point to new developments. New charging technology may double or triple battery life, and improved lead-acid batteries may boost range. Quick charge stations could recharge batteries in 15 minutes. In addition to batteries, advanced flywheels could become an interesting energy storage technology. Finally, new kinds of vehicles are explored and negotiated. Some concepts are deliberately introduced to create a new class of vehicles which is expected to bypass possible initial resistance grounded in comparison with existing vehicles. Initially, most participants looked at high-performance vehicles that could go on highways, as the automobile industry is still doing. But over the past four years a lot of other options have been suggested including so-called neighbourhood vehicles, station cars that could be used at the end of transit lines for renting or leasing, commuter cars that might only go 25 or 30 mph and larger vehicles like battery-powered buses and electric trolley buses.

An important feature of the market of early promises is that many small and new firms start to trade on it. The existence of the market is a prerequisite for getting funding, thus these firms have an interest in developing it further. And they do so by developing new options and concepts. They expect to be able to produce for the niche markets that will evolve, but most of them do not expect to be able to sell for
mass markets. They miss financial strength and distribution facilities. Some of these new firms act as central nodes in the new market. They perceive their own role as platforms. They act as a meeting ground for a large variety of organizations including industry, utilities, government agencies, educational and research institutions. Two examples are CALSTART and the Electricar-Synergy EV Group. CALSTART is a non-profit firm which envisages the creation of a new Californian industry in advanced transportation systems and technologies. California will benefit from that new industry by achieving clean air and a more efficient means of transportation. CALSTART has several programmes including building a showcase EV vehicle with a $7.4 million budget. This car has travelled to many car shows to announce what is possible in California in the field of components development. By early 1993 CALSTART had installed 80 public charging stations and a neighbourhood programme for developing and testing consumer acceptance. Unlike CALSTART, Electricar-Synergy is a company that is actually seeking to produce EVs for the near-term market. The strategy of this company is to bring various needed elements such as technology, producers, consumers and regulators together in an attempt to create a win–win situation. Hence the name Synergy.

The market of early promises is reinforced by a bandwagon of policy measures outside California. Several federal measures have already been noted. Two states in the USA (Massachusetts and New York) decided to adopt the Californian rules, while 11 other states plus the District of Columbia have also committed themselves to adopting the Californian rather than the federal emission standards for cars. Several European cities are considering strong initiatives too, mainly banning ICVs from their centres or reserving special parking lots for EVs. In Sweden a procurement programme has been developed, securing a market of 300 cars for a supplier that meets the criteria established. Partly in reaction to the Californian hype, Japan has quantified plans for the introduction of EVs. In October 1991 the Electric Vehicle Council of the Japanese Ministry of International Trade and Industry (MITI) set up the ‘Electric Vehicle Marketing Programme’ with objectives projected into the year 2000. The programme targets that by that year 200,000 EVs will be introduced into cities.

The Dutch initiative

In the Netherlands an attempt to introduce EVs is also being made, but the Dutch route is quite different from the Californian one. In the Netherlands the approach is to look for and develop specific market niches for EVs through the coordinated effort of all important actors. This is done within a multi-year programme coordinated by an organization called NOVEM which implements and develops R&D programmes for the Dutch Ministry of Economic Affairs. The R&D programme on the rational use of energy is one of them. In November 1990 a so-called ‘practice experiment’ was started in which prospective EV users were given a chance to use an EV for a number of weeks in their regular activities. NOVEM felt that this test was unique since earlier tests were done with experts. Prospective users had never been involved. The aim was to feed results back into the design process and influence the further development of EVs. Together with the practice experiment, NOVEM also initiated a feasibility study. The study was funded by NOVEM, the Environment Ministry and the Ministry of Transport and Public Works. The goal was to analyse three major issues: (1) the value of EVs to specific users; (2) the impact of EVs on use of energy and the environment; (3) possible contributions from Dutch industry to EV
production. To guide and evaluate the results, a Steering Committee was formed, which consists of several ministries, NOVEM and electric utilities.

After the initial problems of finding vehicles were overcome, several cars could be tested in the practice experiment. These included two Volkswagen Jettas and a Chrysler Voyager (a small van) as well as a Volkswagen Transporter. When the cars were offered, the organizers did not have much difficulty in finding companies willing to test an EV for a couple of weeks or months for their own use. Many of them saw it as an interesting option to show their employees and the general public that they were ‘environment-friendly’. There was substantial interest from the press, especially the local press. The experiment became known more widely and as a result many organizations became interested in testing an EV, like the ANWB (the Dutch automobile association) and various municipal bodies. An example of the latter is the city of Amsterdam. The municipality of Amsterdam has held a referendum among its inhabitants in 1992 on the basis of which measures are now being worked out substantially to reduce traffic in the inner city. These measures should make the city more friendly for walking and biking, and reduce pollution. It would, however, not bring noise levels down below standards set by national legislation. Electric vehicles would do so while at the same time reducing local pollution further. The city of Amsterdam, and especially its environment department, were therefore very interested in EVs. They took part in the practice experiment by testing one of the vehicles for a while and intended to investigate, as a next step, factors that would influence acceptance of EVs by consumers.

Findings of the Dutch experiment

The practical part of the experiment ended in December 1991. It produced a wealth of results from a broad variety of users while the feasibility study gave some insight into the general possibilities for EVs in the Netherlands. In the feasibility study, questionnaires were sent to a broad variety of prospective users to assess the economic possibilities of EVs. The results of the experiment can be characterized as a series of articulation processes.

First: articulation of the technology involved. A number of technical problems were identified. The sodium-sulphur batteries allowed for considerably better performance but it was evident that they were not yet fully developed. Some needed repair while the fact that they operate at 300°C necessitates a more complicated (and therefore more expensive) technology. Problems also appeared in keeping the battery at that temperature. The high temperature is also a disadvantage from the overall energy-consumption point of view. Furthermore, heavy vehicles would need a hybrid drive to offer additional power to accelerate.

Second: articulation of user requirement and needs. The driving behaviour of the driver had a considerable influence on the range per battery charge. Careful driver instruction, therefore, can lead to substantial gains. Drivers were highly positive about the behaviour of the vehicles (vehicle dynamics). They found that EVs allowed for quiet, simple and relaxed driving. EV drivers developed a new sense of what car driving is about. In the final report this was labelled the ‘electric driving feeling’. Surprisingly, the needed adjustment to the restricted range turned out not be a problem. Drivers started to plan their mobility in other ways. One important result of the practice experiment was that in the frequent interaction between the various parties a clearer picture of the prospective user was created. Unlike in California, in the Netherlands EVs are not seen as cars for private use. In the course of the
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experiment more and more consensus developed that in the Netherlands ‘fleet owners’ should be the users, ie organizations possessing a number of vehicles that are used for various applications in which the disadvantages of EVs (lower speed, slower acceleration, shorter range) are not crucial. Examples would be taxi companies, service companies, city-distribution centres, wholesalers, etc.

Third: articulation of regulatory constraints. Under the current Dutch road tax system EVs fall under a ‘rest’-category which has the highest rate of all identified categories. Furthermore taxes increase with the weight of the vehicle which due to the heavy batteries is a disadvantage for EVs.44

Fourth: articulation of ways the Dutch industry could profit from a new EV market. Key industries such as automobile manufacturing and battery production are lacking in the Netherlands, but some companies would profit from developing components such as diesel-electric transmission and flywheels. Finally: articulation of environmental effects. During the experiment the energy consumption by the EVs was measured in detail.

The results of the practice experiment were favourably evaluated and NOVEM decided to start a follow-on experiment that would look more into the exploitation and maintenance of use of EVs. Fleet owners would be offered to lease and test a certain number of EVs in their fleet. To this end, a number of vehicles was built that took into account some of the results of the first experiment. The follow-on experiment, therefore, is aiming at imitating ‘real life’ more closely both in terms of vehicles used as well as in terms as the setting in which they are tested.

Comparison of the Californian and Dutch initiatives

In California, at the start the problem was primarily defined as a technological problem. What should be developed was a so-called ZEV that could be widely used. Taken for granted was that everybody has the right to possess his or her own private car and that many families have two or even more cars. The problem then became to develop a policy that would stimulate the development and use of ZEVs for as many applications as possible to create a mass market. A technology forcing mandate appeared to be an obvious route to go. This mandate led to a bandwagon of new initiatives including experiments to stimulate increasing adoption. New firms such as CALSTART and Synergy entered the scene. These firms act as a technological nexus, bringing together variation generators and selectors and engaging themselves in a process of specifying design and selection-environment requirements (including requirements for infrastructure and the development of new user concepts).

In the Dutch situation, people’s mobility was less taken for granted. A broader range of options then presented itself to reduce pollution, including increasing gasoline prices and other taxes. From this broader perspective some defined EVs as a non-solution (even if it were the owner’s only car) as it does not reduce mobility. The various ministries, however, and other actors saw EVs as an attractive alternative among a variety of others when it was targeted at a specific market niche. Especially in the city ICVs perform poorly from the pollution viewpoint due to cold-engine inefficiencies, frequent acceleration/deceleration, inefficiency at low speeds, inefficiencies of the catalytic converter, etc. In such an environment EVs could become an attractive alternative. The experiment was designed in such a way that a broad learning process was enacted involving many parties. The learning process is divided in a graded sequence of phases allowing for step-by-step upscaling. The steering committee of the Dutch practice experiment acted as a platform to evaluate
results, specify requirements and mobilize resources to bring the EV on the targeted niche market, it developed into a nexus, albeit a temporary one.

How to evaluate these initiatives? Until now, both the Dutch and Californian initiatives appear to be a success within their own context. Our main concern is, do they promise to unlock the automobile system? More specific, what kind of evidence can be collected on the effectiveness of technology forcing, experimentation and technological nexus formation for introducing EVs in large numbers?

**Influencing the car system**

*Technology forcing*

Clearly, the Californian legislation triggered a lot of innovative activity, both from smaller companies and from the large automobile manufacturers. The Californian initiative promises a sizeable market and if the large companies will not offer a ZEV by 1998 they are not allowed to sell any product at all anymore. Research from other cases shows that regulation consisting of stringent fixed standards settled for a long period of time indeed induces innovation, while the absence of regulation or the expectation that regulations will change hampers innovation substantially. The certainty provided for a longer period of time allows industry to adjust its investments and R&D policies. Technology-forcing approaches, thus, look like a successful method for stimulating the development of cleaner automobiles (or transport).

However, experiences with earlier attempts of technology forcing also lead to some caution. Technology forcing induces a strategic interaction process between industry and government. If industry thinks it can make a delay without being punished in the end, it will follow that route. White has analysed the introduction of the Clean Air Act in the 1970s which contained technology-forcing standards for cars as well. Industry used exemptions provided and was able to delay the introduction of new technologies substantially. This process is clearly visible in this case as well. The automobile industry has announced on many occasions that they will not be able to deliver a ZEV that can be sold to customers by 1998. They argue that it would already take all their energy even to deliver cars that would meet the ULEV standards of the mandate. Another strategy is to argue that EVs are not clean because they cause pollution elsewhere and thus it would be more effective to trigger innovation in other directions.

On the basis of the work of Ashford, Ayers and Stone it could be argued that governments should follow a ‘fail-soft’ strategy. Government agencies must be strict to create a technology-forcing effect. At the same time, however, if industry shows good faith efforts and still fails to meet the standards, they must not be punished for non-compliance. If firms expect to get punishment even if they have done their utmost best, they will fight regulation. The dilemma for any technology-forcing approach is thus how to keep the regulation pressure high while at the same time ensuring constructive reactions from industry. We argue that experiments could help to circumvent this dilemma.

*Experiments*

A new product like the EV confronts the selection environment with a set of unfamiliar possibilities. New ideas need to be developed how to understand the product. Experiments provide space for the development of such ideas. These ideas cover a broad range of aspects—technology, user needs, infrastructure, needed...
production and maintenance facilities and effects. Ideas become articulated during the experiment in a dynamic way. Electric utilities learn about what service they need to provide, users learn about what they want or need. A striking feature of most of these experiments is how initially a strong focus on existing structures prevails. EVs need to match ICVs. This changed because new vehicle concepts and new mobility concepts were developed. The development of such new concepts depends crucially on experience gained. Another important feature of these experiments is their phased character which allows for learning feedback and upscaling.

Thus, if an experiment is well designed it is the appropriate means for bringing about needed articulation processes and gaining necessary experience. Such an introduction strategy for new technologies we label strategic niche management. We define it as follows: the controlled development and breakdown of protected spaces for new technical applications aiming at market introduction. The protection against early selection can never be complete, but concerns selected aspects. Instead of protection one could also use the term selective exposure to the environment. Strategic niche management is a process in which a new technology and the existing environment can adjust to each other, because the creation of the niches changes the selection environment.

However, a weakness of experiments is that it is difficult to scale the niche up—how to break down created protection while preserving technological developments? The main barrier in the case of EVs is the scale of use and production. A small scale not only implies high production costs of vehicles and infrastructure, it also means that for instance a network for service and maintenance is less likely to be organized. In some experiments upscaling is a defined goal, for which phases are designed in which the scale is increased. Other experiments are designed to have broad exposure of the technology to a wider public, for instance by organizing open days or exhibitions for the general public. Through such initiatives EVs become better known, thus increasing user understanding. The problem of upscaling remains, however. The experiment is a protected and artificial space that still can be dissolved, it is often no more than a temporary meeting ground. This is for instance what happened with EV development in the 1970s. After the oil crises there was a high interest in electric vehicles and in several countries experiments were started to develop them to reduce the countries' oil dependency. Temporarily the high oil prices created pressure for bringing alternatives on the market, but when the prices went down again the interest in alternatives, including EVs, vanished.

Experiments have another weakness as well: they may create an exclusive focus. Experiments could become a prison when firms and institutes consider it as an obligatory point of passage and discourage other new initiatives. This happened to some extent in the Netherlands. Participants of the experiment did not allow other initiatives to come about.

To overcome both weaknesses experiments need some outside pressure, and this could come from technology-forcing regulation. Through embedding experiments in a technology-forcing strategy, experiments could evolve from a device for PR and R&D towards a device that will start the bandwagon of increasing adoption of EVs and eventually this could lead to a shift of the technological system.

Alignment through technological nexus

Activities both in the Netherlands and California have led to the formation of new actors and networks and some actors take on a new identity. CALSTART, Synergy
and the Dutch steering committee are examples of new networks. The electric utilities in California changed their identity through the acceptance of a new role of intermediate between market and technology development of the development. These new actors appear to be of vital importance for the development of niches through experiments and promotion of a market of early promises through regulation. Niches and markets need maintenance and sponsors that are prepared to act on behalf on the new constituency that is built around the EV. This is what CALSTART, Synergy and others provided. They are interested in the process of introduction and act on the metalevel as introduction champions. They create coupling between variation and selection which is of crucial importance for successful shifting of technological systems, as a quasi-evolutionary model would predict.

Conclusion

All three strategies discussed appear to have their own strengths and weaknesses. When used in the right combination they could reinforce each other. Technology forcing could lead to innovation. Some preconditions have to be fulfilled: political support is needed and governments need to follow a fail-soft strategy. The major drawback of a technology-forcing approach is that it may end in a fight between industry and government. Experiments could help avoid this. They provide space for working towards constructive solutions and articulating developments in many directions covering both technology and elements of the selection environment. Thus experiments could help fine-tune the effects of technology forcing. Finally, if governments are the only ones who attempt to bring alternatives to the market, they are bound to fail. Other actors need to join their course and in particular new actors who could serve as a technological nexus are needed to come about. A technological nexus provides amplification of the first two routes and we would argue are of crucial importance for the sustaining of the new world generated by experiments and technology forcing. This new EV world looks fascinating and provides hot news for newspapers and magazines. Their stability is not yet guaranteed. Irreversibility could evolve but is not assured.

The groundwork for shifting technological systems can be prepared. The outcome, an actual shift, depends on a coming together of a complex set of factors and actors and many interactions which cannot be predicted. They can be organized, though, if one sees the process of introduction and change as a joint learning process driven by interactions on a market of early promises.

Notes and references


9. Electric vehicles display characteristics which are quite different from internal combustion cars and would if introduced in sufficient numbers change the knowledge base, supply and maintenance structure and the car culture substantially. Following the evolutionary analogy they will gradually replace internal combustion cars through higher production frequencies and the creation of a new selection environment which will make electric vehicles more adaptive.


20. The sections about electric vehicle activities in California are based on a country report on the USA by Boelie Elzen (May 1994). This country report is based on documentation and interviews.


23. This is why European manufacturers like Volvo and Volkswagen have design centres in California.


27. This paragraph is based on personal communication with Gordon Allardice and Mike Clement, Chrysler Corporation, 22 November 1993; Roberta Nichols and Chuck Risch, Ford Motor Company, 22 November 1993; and Paul Patak, General Motors, 23 November 1993.


29. The following paragraph is based on personal communication with Dan Fitzgerald and Christina Haslund, Pacific Gas and Electric Company, 5 November 1993; Richard Schweinberg, Southern California Edison, 2 November 1993; Winston Ashizawa, Sacramento Municipality Utility District,
10 November 1993; and Tom Doughty, LA Department of Water and Power, 1 November 1993.
31. Alfred Altman and Thomas H Floyd, _Emission Limited City Cars for Metropolitan Areas_, Society of Automotive Engineers (May 1968).
34. Personal communication with Ulrich Steger, formerly with Volkswagen AG, 9 February 1994.
38. Volvo Car Corporation, company brochure.
39. This section is based on personal communication with Glen Perry, CALSTART, 1 November 1993, and Bob Garzee, Electricar-Synergy, 8 November 1993.
41. Personal communication with Anders Lewald, NUTEK, 2 September 1993.
43. The sections about the Netherlands are based on R Hoogma, _De ontwikkeling van elektrische auto's in Nederland_, Master’s Thesis, University of Nijmegen (1992); Boelie Elzen, Johan Schot and Remco Hoogma, _De toekomst van de elektrische auto in Nederland_, internal report, University of Twente (1992); and NOVEM, _Het elektrisch voertuig op proef. Ervaringen uit de praktijk_, Utrecht (1992).
44. Since 1993 the purchase of an EV is subsidized with FIS 5000. Commercial users are also offered financial benefits in connection with the amortization of EVs.
47. Ashford _et al_, op cit, reference 45.