5. Identifying *Loci* for Influencing the Dynamics of Technological Development

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INTRODUCTION

New technologies eventually get embedded in society, and their impacts depend on the processes of contextualisation. In this overall co-evolution of technology and society, a variety of actors are interested in influencing technological change in terms of their own goals, be it market success, strategic advantages, quality of life, sustainability. It is through the actions and interactions of these actors, guided by their assessments and occasional, more or less systematic anticipations that technologies evolve and are adopted and adapted.

A challenge, not just for technology developers, but increasingly also for policy makers and critical societal groups, is to influence technological change at an early stage, when irreversibilities have not yet set in and one can hope to sway the balance between desirable and undesirable impacts. The dilemma involved has been articulated by Collingridge (1980): when control of technological change is still possible, knowledge of eventual impacts (and how these will arise) is so limited that the direction to go is unclear. His knowledge and control dilemma becomes less stark if one looks at the whole developmental process and tries to understand the dynamics and evolving patterns. Constructive Technology Assessment (CTA) addresses this specific argument: understanding of heterogeneous and often contested developments allows constructive interaction and gradual and cumulative shifts in desirable directions (Daey Ouwens *et al.* 1987; Rip, Misa & Schot 1995). At the time, this was a programmatic claim. In a later state-of-the-art paper, ongoing anticipation and open-ended learning were emphasised, and a number of CTA strategies were identified and discussed (Schot & Rip 1997).

One could argue that Collingridge's dilemma is still with us: the emphasis on learning does not imply that the right directions will be found in time (also because attempts to alter directions will be contested). Phrased in this general way, it is part of the *condition humaine*. A closer look at how technological change occurs in our societies, combined with a shift in perspective (and thus ambition) on how to influence technological change, allows us to improve on Collingridge and on earlier CTA strategies. The key notion is that there are preferred *loci* for influencing; windows of opportunity as it were. In this paper, we develop this notion for the specific context of technological developments initiated in firms (or other technology-promoting organisations) – a context which is dominant in the present era. The approach is generally applicable, however.

To set the scene, we first introduce further dilemmas (or paradoxes), and note that such dilemmas are somehow resolved in ongoing practices. Attempts to do better have to link up with such ongoing practices, and recognise the dynamics involved.

A first tension (or dilemma, or paradox) is the difference between functionalities originally envisaged for a technology and the eventually dominant ones. The functions the telephone now fulfils are very different from the ones envisaged originally: communicating between operations in the centre and in the periphery of the town, and piping concerts from the concert hall in the city centre to the suburbs (Fischer 1992). In other words, intervention strategies cannot simply be based on actors' intentions at the time, and their predictions of eventual achievements.

Especially in R&D-based innovations, the development trajectory optimises the new process or product as such, but its eventual success requires re-contextualisation, a process which cannot be anticipated fully, let alone determined, at the earlier stages of the trajectory (Verbund sozialwissenschaftliche Technikforschung 1997, p. 20). A striking example is the negative reception, by the deaf community, of cochlea implants (Garud and Ahlstrom 1997). This example also shows that the problem is not just a cognitive one (how to anticipate the unpredictable), but also a socio-political one (technological development is a matter of insiders, but will be exposed to outsiders). This is a dilemma, and not just a matter of blinkers, because there are costs involved in taking wider contexts into account at an early stage (Deuten *et al.* 1997).

The second tension (and paradox) strikes at the heart of the claim that understanding the dynamics of technological change and its embedding in society will allow intelligent intervention. Recent sociology of technology, together with the empirical part of economics of technology, provide a rich (if sometimes patchy) understanding of the dynamics of technological development and its embedding in society (Rip & Kemp, 1998). But this understanding is essentially retrospective, based on historical case studies and surveys. The patterns and regularities found in this way may be extrapolated into the future, but at a risk: circumstances may be different. In fact, they will be different already because of preceding technological developments and their dynamics, and their being recognised and understood for what they are.

Since actors will act strategically, including action based on the understanding of earlier dynamics, this may then shift the dynamics into a new pattern – which may even undermine the basis for their action. Self-negating prophecies, as in the case of warnings that are heeded, are an example of such a shift.

An intriguing further example is provided by Moore's Law, which has held for more than three decades now because actors direct their efforts and co-ordinate their actions with the continuation of Moore's Law as the frame of reference (Van Lente & Rip 1998). As a news report in *Science* (1996) phrases it: 'Researchers around the globe are working furiously to extend the life of Moore's Law by coming up with alternative chip-patterning techniques for use when current lithographic tools hit the wall.' It is exactly because of such efforts, driven by innovation competition, that advances in chip technology remain predictable. As soon as firms decide to adopt another strategy, and go for alternatives, Moore's Law would lose its hold, and thus its validity.

Does this imply that the insights of sociology and economics of technology are to no avail? Indeed, sociologists, economists and political science scholars of technology should be modest about their contribution. But there **is** a contribution: first the negative one, the message that the ambition of guaranteeing the achievement of a desired goal is futile; and second, it specifies ways to modulate ongoing dynamics in the hope of getting closer to one's goals. This is like Charles Lindblom's productive 'muddling through' approach (cf. Lindblom & Woodhouse 1993), but with an added point: understanding the dynamics of development allows one to identify opportunities for intervention, and specify how such interventions can be productive. This will not resolve all complexities of anticipation and intervention, but will go some way to mitigate them.

As a first step, therefore, we introduce insights from technology dynamics. Concretely, we will use the metaphor of an innovation journey – which actually refers to the underlying phenomenon of emerging path-dependencies – to analyse dynamics (contingencies as well as recurrent patterns), and show that one can reconstruct the innovation journey in terms of actors' perspectives and actions, as well as interactions and their outcomes.

THE FIRST STEP: USING OUR UNDERSTANDING OF TECHNOLOGY DYNAMICS TO CREATE A MAPPING TOOL

Recent sociology and economics of technological change offer important insights (Bijker *et al* 1987; Dosi *et al* 1988; Tushman & Anderson 1997). For our purpose, we select two main points.

First, the recognition of contingencies and the tension with the need to anticipate, somehow. In Van de Ven *et al.* (1989), the studies of product creation processes within a firm are presented as innovation journeys with their setbacks and shifts. There is no path given in advance, the actors create a path by walking (sometimes stumbling along). Such innovation journeys include tentative anticipations on embodiment in society, and this is increasingly important, e.g. for biotechnology firms (Rip & Van de Velde 1997). Actors, e.g. the focal firm, will reduce the complexities by creating a concentric picture of the firm in increasingly wider environments (Deuten *et al.* 1997). If one takes technology, rather than a firm, as the focus, a variety of organisations (firms as well as public agencies and NGOs) are important. Non-linearities, branching, and path-dependencies then become even more striking (Rip 1993). In other words, anticipations by firms and other technology-developing organisations should take these complexities on board.

Second, and in spite of the *prima facie* contingencies, patterns emerge through linkages, alignment and networks. This holds for innovations, as in the well-known contrast between regular (or incremental) innovations and 'architectural' (or radical) innovations, where competencies as well as market relations are disrupted and have to be built up again (Abernathy & Clark 1985). And it holds for sectors and regimes, as in Garud (1994)'s analysis of 'fluid' and 'specific' structures, and Callon's (1998) closely related distinction between 'hot' and 'cold' situations. The importance of linkages and alignments extends beyond innovations and industry structures to the embedding of technology in society, which includes mutual adaptation with other products and actors, and articulation of acceptability (Rip 1995).

Generally speaking, there is co-evolution of innovations and industry structures, and more broadly, of technology and society, and there are definite patterns in the co-evolution (Rip & Kemp 1998). While there will always be contingencies, there is also linkage creation, increasing alignment, and thus a certain amount of predictability, or at least, reasonable foresight.

Our question about intelligent intervention can now be reformulated, in a first round, as one of anticipation on eventual contextualisation of a novel technology (as part of the innovation journey), and identification of possibilities for intervention. A mapping and diagnostic tool is necessary to do this, and this implies that the complexities of the real world have to be simplified into stylised facts, which must be sufficiently rich to capture complexity, but also simple enough to allow application across a variety of cases.

To develop such a tool, the first simplification is to focus on typical activities in innovation journeys. These activities (like invention, development, prototyping, introduction, diffusion) may occur sequentially, but always with feedback and feed-forward loops. Also, the identity of the 'travellers' (the actors as well as the technological options being developed) may change in the course of the journey. The case of the telephone is a clear example, but it is visible in almost all innovations. Anticipation on selection environments, and more generally, on context is important, and this may well be internalised and institutionalised. Test laboratories and consumer panels being, by now, obvious examples (Van den Belt & Rip 1987).

Actors involved with developing and introducing a new technological option will immediately recognise this way of capturing the dynamics of development. But it has a definite 'concentric' bias, in the way it starts with novelty creation and follows its journey over time and across space. As an analyst, one could, instead, focus on sectors and regimes from the beginning, or even more broadly, on evolving socio-technical landscapes, or techno-economic paradigms as Freeman calls them (Rip & Kemp 1998). Such a non-concentric view is not biased toward success, and this is important because many new options die at an early stage. For the question of influencing overall developments, attention to reviving options left by the wayside, or shifting the success criteria more generally, is important (even if it may well be difficult to nurture such alternatives so that they become real options).

This argument about actors and analysts is mirrored in practice by the contrast between insiders (who will take a concentric view) and outsiders (for whom the new technological option is only one item, and possibly an unwanted intruder) – cf. Garud and Ahlstrom (1997). Monitoring of the environment is done by the insiders. While this monitoring has an increasingly broader scope as the innovation journey progresses, there will also be surprises – when the environment strikes back, and upsets incipient paths and path dependencies.

These considerations set the scene for the second simplification, which addresses the problem of keeping the overall picture in mind, in spite of a concentric bias. The so-called 'techno-economic network' mapping approach of Callon *et al.* (1992) is a tool to map linkages and networks as they occur, and reminds the analyst (and then the actor) of the whole breadth of aspects involved in innovation. The simplification, to keep the mapping exercise manageable, is to reduce these aspects to four 'poles' to characterise activities: science, technology, market, and regulation, each of them operationalised in terms of dominant intermediaries and interactions (say, the four Ps: publications, patents, profits, and performances) (De Laat 1996). These 'poles' reflect the historically evolved, more or less institutionalised situation in present-day societies. They cannot cover all the details and complexities, but are a useful first approximation.

The two simplifications together: the journey metaphor and alignments categorised in terms of four 'poles', allow a useful visualisation of actual innovation and application/adoption in a two-dimensional scheme (Figure 5.1), with progress along the path of the innovation journey on the vertical axis, and the Science, Technology and Market/Society poles of techno-economic networks on the horizontal axis. (Figure 5.1, shows only three poles, but adds 'regulation' and 'society' to the market pole to indicate that there are more aspects.)

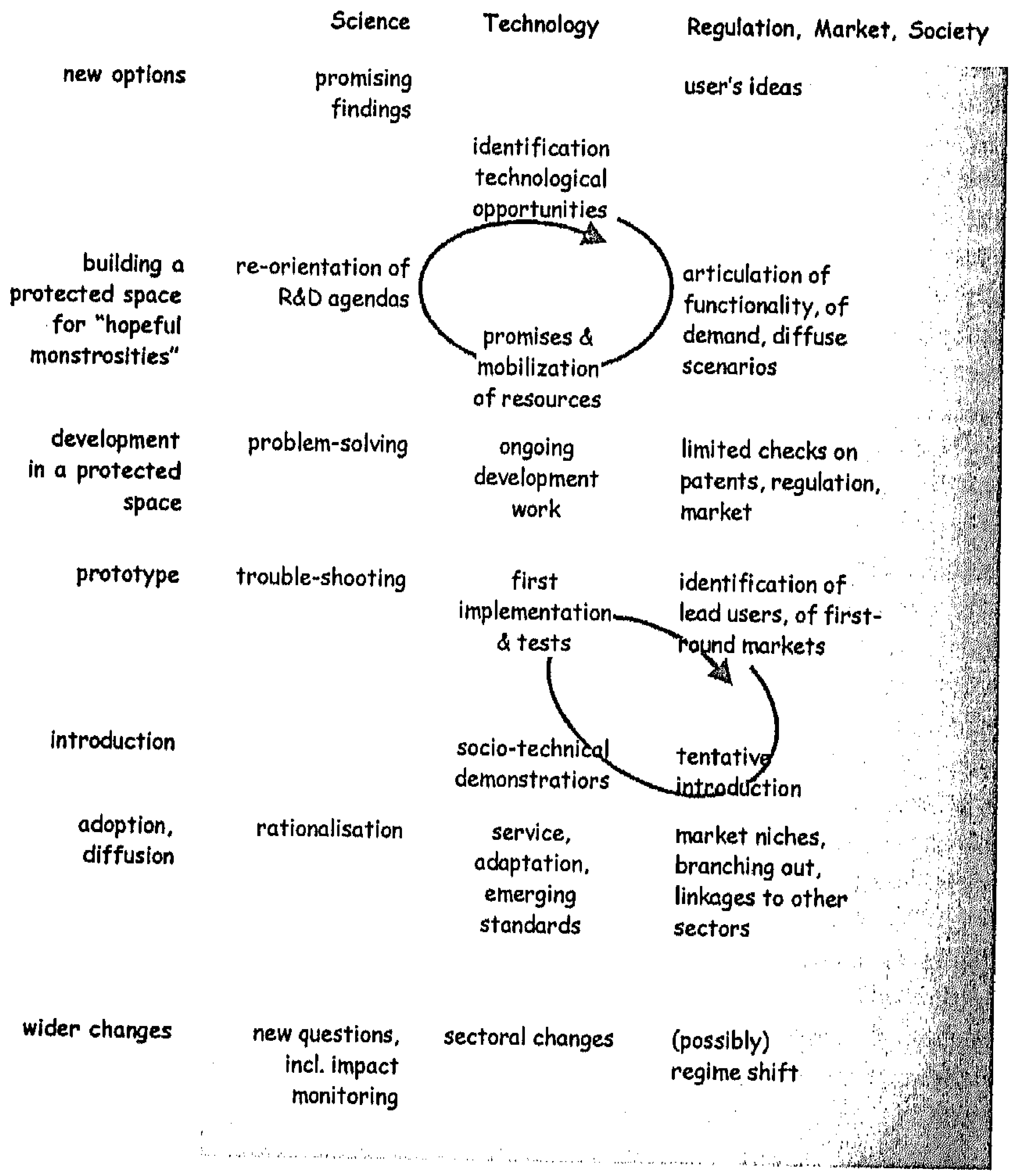
This visualisation covers a dynamic process, and allows progressive snapshots of an evolving situation. In the beginning, only the top of the map is in place, and the remainder is still in the future. Over time, as the innovation journey progresses, further parts of the map materialise. In the early stages, the market/society pole only figures in terms of market studies, early promises, and other expectations. Such expectations guide actions, but precariously: they may construct a 'house of cards' that breaks down when the effort to maintain it becomes too heavy (Van Lente 1993).

The advantage of introducing this mapping tool (in spite of its simplifications) is that it visualises the present as well as the future. Actors tend to project a linear future, defined by their intentions, and use this projection as a road map – only to be corrected by circumstances. The present mapping tool forces actors to consider the non-linearity of evolution, accept the complexity, and thus become more effective.

Both insiders and outsiders can profit from this mapping tool (and the understanding of the dynamics of technological change which informs it). Insiders can, and should, forget their linear projections, and accept that their attempts to make a difference cannot always be successful. Outsiders are invited to consider opportunities for intervention, defined by the dynamics of the innovation journey.

We think three types or clusters of activities can be distinguished where the innovation journey enters into a new phase: build-up of a protected space, stepping out into the wider world, and sector-level changes, and we will arrange our discussion accordingly.

Figure 5.1 Innovation Journey in Context



BUILDING-UP A PROTECTED SPACE FOR 'HOPEFUL MONSTROSITIES'

The simplified story-line of the innovation journey-in-context starts with the identification of a technological opportunity: a new option, or the pressure to find a solution for a problem. Such options may derive from R&D findings or scientific advance in general, but other sources remain important. The story of the zipper is a case in point. 'New combinations' (to use Schumpeter's suggestive phrase) are important. Suggestions or questions from (professional/knowledgeable) users can also identify opportunities, as Von Hippel (1976) has made clear.

The role of science varies, but has often to do with the discovery or modification in the laboratory of an effect which is linked with potential application. An example is the discovery of high-temperature superconductivity, which led to speculations about more efficient magnetic trains (eventually, other applications of this new laboratory phenomenon turned out to be more realistic, e.g. detection systems for very weak magnetic signals).

In the pharmaceutical industry, the search for 'leads' is a recognised activity, and this has to do with the level of articulation of functions to be fulfilled: (re)searchers have a good idea of what they should be looking for. In other sectors, the articulation of functions, and thus search for opportunities, is more *ad hoc*. From the world of science, there is a continuous stream of ideas and promises, but with reference to broad and diffuse functionalities only (for membrane science and technology, Van Lente & Rip (1998) provide a detailed study of the dynamics).

For our analysis, the key point is that such technological opportunities start out as 'hopeful monstrosities' (Mokyr 1990, Stoelhorst 1997): full of promise, but not able to perform very well. Actors will make more specific promises (to sponsors) to mobilise resources to be able to work on the technological opportunity, and nurture it into a semblance of functionality – what is called 'proof of principle'.

Such promises anticipate, and thus further articulate functions and possible societal demand. Because they also specify what the material, device or artefact should be able to do ('performance'), this identifies and stabilises an R&D agenda. As Van Lente (1993) phrased it, a promise-requirement cycle is started up and shapes the trajectory.

There will be a lot of hype and hand-waving, and actors will take-up different positions (exaggerate, or underplay the promise for fear of creating disappointments and a backlash). Quality control of the rhetoric is important (for all actors), but cannot, by definition of the situation, be definitive. Certain patterns have become recognisable, though (the 'gee whizz' factor; goldrush/bandwagon, and decline when the 'nomads' have travelled on). We note in passing that quality control is also necessary on the part of resource providers, within a firm or in the public domain, who often have a portfolio to fill with promising projects, and are eager to find them.

The net effect of the networking and resource mobilisation is the emergence of a protected space for promising R&D, for developing the technological opportunity. Part of the protection stems from a (precarious) agreement over a diffuse scenario about functions to be fulfilled and their societal usage. The nature of the protected space, its boundary agreements, the rules and heuristics derived from the promises that were made, together determine choices and directions. Work within the protected space thus proceeds according to its own dynamics, with only occasional checks with the scenario of usage (if at all).

The advantages are clear; they are recognised and consciously applied, in an extreme version, as skunk works, as when IBM constituted a separate group, with its own resources and outside regular management control, to develop its PC. (A practice pioneered as a conscious management tool by Lockheed aircraft company in the 1940s (Valéry 1999).)

The risks derive from the fact that the diffuse scenario which legitimated the creation of the protected space remains diffuse. This may create problems later on, which require repair work and/or (unexpected) shifts in direction. And sometimes, the promise will turn out to be empty after all.

STEPPING OUT INTO A WIDER WORLD

At some moment of time, a decision is taken (or emerges) to go for prototypes or other attempts at demonstrating a working technology. Activities include prototyping, exploring/optimising production, trouble shooting and rationalisation through further research, implementation and learning about usage, and preliminary market testing. In the case of biotechnology, regulation and acceptability also become real issues, and might direct efforts in particular directions.

These activities are much less self-contained than the earlier research and development, and fall prey to intra- and inter-organisational tensions. Different interactions and management styles are called for. Garud and Ahlstrom (1997) contrast the 'enactment style' of the insiders with the 'selection cycles' in which outsiders are involved as well. The complexity is all the more troublesome because time pressures are often very large at this stage. As Deuten *et al.* (1997) emphasise, the need to learn (in order to introduce the innovation successfully) may be great, but there may not be space for learning.

A useful way of assessing the complexity is to map the sociotechnical couplings that occur, for example with other actors in the chain, with government bodies, with third parties (for example, consumer groups), and check for balance and possible path-dependencies. Some of these couplings are already present for other reasons (e.g. alliances), or have been made at an earlier stage (Deuten *et al.* 1997).

With the tentative introduction of the new product or process, with a few customers ('lead users'), or in a 'societal' experiment (often in collaboration with public authorities, as in the case of electric vehicles), the complexity increases, but also the opportunities for real-world learning and subsequent modification of the product. Because specific sociotechnical couplings are introduced, path dependencies may occur: certain niches are created for learning, so the kind of learning depends on the niches, and this may not be adequate to the demands and selections in the wider world. In addition, the visibility of the project/product increases which will have repercussions.

Sociotechnical demonstrators are important, but not always possible in a direct way. For some sociotechnical systems, social experiments are done: real-life, but experimental use, to learn about the system, about use, and about articulation of demand (see Schot *et al.* 1994, Weber *et al.* 1999 on electric vehicles). These are full-blown sociotechnical demonstrators, in a situation where the devices are available, but the system is still uncertain.

When the devices are still uncertain, there can be trials with prototypes. Often, this is only possible in collaboration with an intermediate or professional user, who as it were provides the system, at least, the system as s/he is utilising up till then. So the 'real life' aspect becomes more dubious.

Market introduction, an important concern for marketers and higher levels in a firm, is thus a gradual process rather than a point decision. The non-linear nature of adoption of new products and technologies, while recognised retrospectively, requires lateral thinking, away from the present functionalities and prospects of the product. An interesting example is the use of industrial enzymes not for the projected improvement of main industrial processes but to stonewash denim for jeans - a niche market and an occasion to get production and utilisation experience with such enzymes relevant for broader industrial usage. An earlier example (instructive in many other ways as well) is how poly-ethylene became a successful polymer – because of non-critical demand provided by the unexpected Hula Hoop craze in the middle 1950's (McMillan 1979).

The 'market' is neither one-dimensional nor homogeneous, and demand is only gradually articulated in response to supply: in the late 19th century, there was no articulated demand for automobiles, and producers gradually learned to distinguish relevant product attributes in interaction between new technical possibilities and customer responses (Abernathy *et al* 1983). The point continues to be important, in the large as with modern biotechnology and multi-media technology, and in the small (Green 1992, Bower and Christensen 1995).

There must be something like a protected space for the new product, so that it will survive an otherwise too harsh selection environment. At the same time, limitation to the particular protected space creates a product that survives only within that space. This may well be the final outcome: a product existing in one market niche; fuel cells, in spite of their recognised general promise, really only functioned in space applications (Schaeffer 1998). But introducers of new products often want more, and explore further market niches. In general, a strategy of ever widening 'niche management' is in order (Weber *et al.* 1999). In the case of electric vehicles, the differential success of various introduction strategies support this claim (Hoogma 2000).

SECTOR-LEVEL CHANGES

The new product and/or new technology branches out in various ways. There have been some retrospective studies of these processes: of the telephone, developed with a view to other uses (Fischer 1992, de Sola Pool 1983); electric lighting between 1880 and 1930 is another interesting example (Marvin 1988; Nye 1990). Such historical studies are very important to broaden the perspective and create a sensibility, with actors keen on immediate success for their projects, for cross-linkages and shifts.

Branching of niches leads to niche 'piling' (Schot 1998): heaped on top of each other, the niches add up to something more than their simple sum. There is a cumulative effect of further varieties of application: suppliers orient themselves to the new technology, economies of scale and scope are exploited, and recognition, by users, of further possibilities (think of telephone and electric lighting again) creates new sociotechnical linkages. The sector starts to change, and its relations with other sectors change. The latter can become so important that the technology driving such changes by being taken up widely is called a pervasive technology, and characteristic of a new techno-economic paradigm (Freeman 1992).

Path dependencies occur for a variety of reasons: increasing returns (Arthur 1996), *de facto* standard setting (David 1985), sunk investments in competencies and culture (Burgelman 1994, North 1990). The outcome is the advent of a technological regime: an emerging and then stabilised set of rules guiding technological development and its embedding in society (Rip and Kemp 1998, Kemp *et al.* 2000).

The development of computers in the 1940s and 1950s (and beginning of 1960s) provides an interesting example. Computers started out being part of existing computing and automation regimes, and only gradually developed their own dynamics (linked to software, and in particular programming with the help of programming languages, and an infrastructure including compilers, rather than by creating physical linkages). By 1965, the tables were turned, and the computer plus software led developments rather than having to adapt. A computer regime was established (Van den Ende & Kemp 1999).

As with emerging rules and institutions in general, a reversal occurs in which a precarious product of actions and interactions of actors, requiring care and repair all the time, turns into a stable regime which orients actions and perceptions. This is the way to understand how design hierarchies become established (Clark 1985), and the regime concept can be used to broaden the notion of design hierarchy (Van de Poel 1998).

Cumulative effects may thus lead to the emergence of new regimes and/or shifts in existing regimes. This is a multi-actor, multi-level process, in which no single actor can sway the balance intentionally. Actors will attempt to do so, of course, jockeying for position in the newly emerging games and regimes, and involving themselves in strategic alliances. In standard setting in information and communication technology and in consumer electronics such processes are very visible. While the actors involved, as well as the media reporting on the struggles, may think in terms of heroic stories in which power and cleverness of the actors determines the outcome, the cumulative process of increasing interdependencies and sunk investments is the major explanation.

HOW TO INFLUENCE DEVELOPMENTS

If actors want to exert influence and change an emerging path in another direction, they face the momentum that has been built up and the loss of malleability because of increasing alignment. Internal actors are constrained by their inclusion in the dynamics, and external actors have to overcome the distance between inside and outside (cf. Garud & Ahlstrom 1997). A contest of forces may ensue, and one which may become larger than the original issue. This is how radio-active waste became an issue which may well subvert the further diffusion of nuclear energy production (Albert De La Bruhèze 1992), and the present controversies about genetically modified products - Frankenstein food - may lead to similar impasses.

The alternative approach is to see path dependency as an opportunity. If one can help shape the path and its ensuing dependencies at an early stage, there is no need to interfere later on: the irreversibilities along the path will take care of maintaining direction.

To do so in practice, the first requirement is to understand the dynamics of such developments in context. In general, it is important to enrich the innovation journey, as it occurs anyway, by anticipations and feedback. Anticipations of outcomes (including impacts of the technology on society) must be a ongoing concern, rather than *ad hoc* efforts to persuade a sponsor or regulator that the journey can continue. The learning made possible through scenarios (especially important at an early stage), through socio-technical demonstrators, and through the recognition of niches, must feed back into the development work.

Particularly interesting is the identification of preferred *loci* for intervention: just before 'gelling', it is still possible to exert influence, while there is some assurance that a real difference will be made because it will become part of the trajectory. Three such *loci* are visible in our present analysis: when a protected space for early development emerges; at the first introduction into the wider world; and when niches start to branch and pile.

The second requirement is intelligent intervention: it is not brute force but playing with the dynamics which will make a difference. This applies to attempts at intervention by outsiders as well. Modulation (with some orchestration) of the dynamics appears to be the right approach. With the many actors involved, and the heterogeneity of their interests and strategies, there is no guarantee that a coherent direction will evolve. A 'shadow of authority' may be necessary to break through impasses. Credibility pressures, for example in relation to environmentally-friendly products and processes, can play such a role.

Authority and credibility pressure are also routes through which public interest considerations about desirable directions can be brought to bear on the dynamics of development. While this indeed happens, for example in technology forcing regulation by governments and in public debates and consensus conferences about new technologies and their eventual impacts, there are also limitations deriving from the outsider position.

Intelligent intervention works out differently for the three *loci* we identified, because the dynamics and the extent of embedding in society are different. Insider and outsider interventions will be shaped differently, of course, but one can formulate general approaches.

Locus i

Modulate promise-requirement cycles, and the attendant resource mobilisation activities, so as to build a forceful agenda (for work in the protected space) on which general interests appear in addition to (short-term) actors' interests. Assess the balance of sociotechnical couplings, also from the point of view of desired societal aims. It is important to force some articulation of the diffuse scenario, even if this cannot be done with the help of a 'sociotechnical demonstrator' yet. There is nothing to demonstrate at this stage. But one can present ideas and expectations, and learn from responses by prospective users, opinion leaders. Socio-technical scenarios could be built as a kind of prospective sociotechnical demonstrators.

Locus ii

Modulate the introduction of a new process or product, seeing it as an experiment (in society rather than in a laboratory) through which one can learn about the technology and its impacts. As Weber *et al.* (1999, p. 11) note: 'Demonstration projects often aim at convincing others of the usefulness of a certain innovation, while [one should] aim to explore and learn in a quasi-controlled manner about the practicalities outside of the R&D setting.' In the cases they have studied in the domain of transport (including electric vehicles), such learning does not always occur because of short-termism and political exigencies.

Locus iii

Modulate the cumulative processes which may lead to regime changes. This is the most uncertain and precarious of the three *loci*, because of the involvement of many actors in many places, and the limited influence each individual actor can have on the outcome. Hoogma (2000) has developed a metric for niche creation and expansion. He shows, for the introduction of electric vehicles in a number of countries, that conforming to existing patterns of use and/or existing socio-technical configurations is necessary as a first step. Van de Poel (1998), after analysing eight cases of regime change, emphasises the twin requirements of creating openings for transformation by undermining the legitimacy of the existing regime, and building a technical agenda and developing technical alternatives to fill up the space so created.

In this chapter, we have not addressed the full scope of the challenge how to influence technological development at an early stage. We were able to identify three *loci* where anticipatory intervention can make a difference, but there are other such *loci*. Test labs, for example, are an accepted way of anticipating on later contexts, and can be seen as another instance of 'gelled' alignment, now as an institution rather than a stage in a process (in quasi-evolutionary terminology: an [institutionalised] nexus between variation and selection, cf. Van den Belt & Rip 1987, Schot 1992).

Our focus has been on industrial innovation, and in particular on new materials, devices and other products. In the development of large systems, on the other hand, other features may be prominent because of the larger need for co-ordination. The overall approach will be the same, however: instead of a rational planning and management approach, the vicissitudes of development and emerging alignments will be the starting point. (Interestingly, within RAND Corporation, the home of systems analysis, this same point was made and supported through case studies by a small group of analysts including Kenneth Arrow and Richard Nelson; see Hounshell 2000.)

Our analysis indicates what productive requirements will be on anticipation (e.g. articulate diffuse scenarios) and on intervention (modulation rather than force). There is, however, no guarantee that enlightened intervention will lead to desirable outcomes. In other words, we have not resolved the assessment-and-control dilemma. What we have done, instead, is to reformulate it, from a stark contrast between knowledge and control at the beginning and at the end, to ongoing processes of anticipation and intervention. The further step was to emphasise the importance of learning and modulation, as two sides of one reflective process.

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