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Processes of Technological Innovation in Context – and Their Modulation

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Technological innovation in context has been studied by economists and sociologists of technical change and innovation. I shall present the insights and perspectives from this body of literature (including some of my own work), in order to highlight the dynamics of technological innovation processes and the possibilities to influence them – by managers, as well as governmental and societal actors. These actors often work with a limited view of the complexities of technological change and innovation, and they might do better if they were to use recent insights, as I have argued previously (Rip, 1995). Thus, a further topic, visible between the lines of my main exposé, is the relation between the 'theory' – i.e. insights from social scientific studies – and the 'practice' of policy or action.

More than thirty years ago, the American economists Nelson and Winter published an article about what a 'useful theory of innovation' might be, and they sketched an evolutionary approach: new technological options are introduced all the time but only some of the firms doing so would grow, depending on selection environments (Nelson and Winter, 1977). The late 1970s and early 1980s was also the time when national governments started to articulate technology and innovation policies. The Netherlands White Paper on Innovation (1979) actually used the Nelson and Winter distinction between technological trajectories and selection environments to categorize and, to some extent, derive policy measures and policy tools: stimulating variation,

supporting selection, and improving interaction between variation and selection. Thus, theory was applied by policy makers, albeit in simplified form.

Why go back to the late 1970s? One reason is that the Nelson and Winter article was a seminal publication, and later work continues to refer to it. The other reason is that the example of the Netherlands White Paper shows interesting links between an understanding of the dynamics of technological innovation and the identification of opportunities for intervening; in this example, through policy measures. Intervention requires simplification, not just the (hopefully productive) reduction of complexity that any theory entails but also translation of projected goals into concrete attempts to make a difference, for which theory can be mobilized.

In doing such translations, policy making draws on a modernist philosophy, almost by definition. One indicator is the strong 'instrumentalist' push for robust methods that allow the policy maker to make a difference, to exert influence – in other words, act at a distance. The subtitle of Pressman and Wildavsky's (1984) book, 'How Great Expectations in Washington Are Dashed in Oakland', summarizes both the modernist thrust and its limitations. The instrumentalist thrust may already be counterproductive on its own terms, when its neglect of the complexities and the own dynamics of the world out there in Oakland reduces the chance of achieving its objectives.

Still, modernist approaches continue. This is linked to strong presumptions about a envisaged better world, where the world-as-it-is appears to be an obstacle to be overcome by dedicated action. But, if we live in a non-linear world where multi-actor interactions and their sometimes unpredictable outcomes determine what happens, such an approach, predicated on the idea of an actor working to realize a goal and achieving it because of his/her efforts, will by definition be unproductive. I am not implying that individual policy makers are never sensitive to the limited scope of their action among a multitude of actions and interactions. The structure and culture of the policy environment forces a modernist approach upon them, whether they identify with it or not. (Rip, 1998)

The modernist philosophy highlights the heroism of the policy actor vis-à-vis the system. But, there is a variety of actors and roles, and eventually a 'distributed coherence' for which no single actor is responsible. Some actors may contribute more to such self-organization than others but there is no general rule. If dominant positions occur, these cannot be taken for

granted and are, in that sense, contingent. Instead of steering from a position of strength (which includes authority), there are mutual translations. The policy actor is one of the actors – no more, no less. But the policy actor's link with the *res publica* does create a special responsibility. Even if a policy actor cannot do much more than induce or modulate ongoing self-organization, s/he can be held accountable. And the 'shadow of authority' that goes with the position can have effects, even if these are not linearly derived from the authoritative role.

While I focussed on policy making and implementing, my point about modernist approaches is general. Managers of different ilk are also modernists – although it is easier for them to become reflexive and even turn to post-modern approaches because they are much closer to ongoing processes (Visscher & Rip, 2003). 'Post-modern' is probably too strong a term, though.

In general, for policy actors and for managers, productive intervention, in the large and in the small, remains a challenge but not in a simple modernist fashion. A few authors have offered relevant perspectives and conceptualisations, such as analysis of transitions from 'fluid' to 'specific' situations (Garud, 1994) or from 'hot' to 'cold' situations (Callon, 2002). Evolutionary approaches are important because these emphasize the contingent character of eventual stabilisations. Relational approaches are another way to thematize non-modern management approaches. To intervene in fluid and distributed processes should be seen as a matter of modulation (Rip, 2006a). Brute change efforts are an extreme version of modulation and one that can be productive only in extreme circumstances such as a war economy.

In this chapter, I shall sketch the general perspective, based on an evolutionary approach to technological change, then introduce the notion of an innovation journey (after Van de Ven et al., 1999), identify specific opportunities for modulating ongoing processes, and in the conclusion come back to the role of government.

THE QUEST FOR UNDERSTANDING: AN EVOLUTIONARY APPROACH

Why go for evolutionary theory? Evolutionary economics and the related sociology of technological change continues to be of great interest to policy makers but is not really

accepted by mainstream economics. In my view, this reflects less on the quality of the evolutionary approaches than on the limitations of mainstream economics itself, which is too far removed from what happens in the real world (at least, with respect to technological innovation). Economics has always had problems treating dynamic situations, and technological innovation is dynamic almost by definition.

The need for evolutionary theory derives from the recognition that technological innovation always implies a change with respect to what existed and, to some extent, a break with what was usual. In other words, a new technological option is a 'novelty' just like a mutation in Darwinian or other biological evolutionary theory. And like a mutation, the new option might well start out as a 'hopeful monstrosity' (Mokyr, 1990; Stoelhorst, 1997) that must be nurtured to improve, grow and survive the harsh selection environments – sometimes, the organization in which the novelty arises, is already a harsh selection environment.

Such an evolutionary theory is directly relevant to the issues of policy making and management. Its relevance goes deeper than policy makers using such insights to articulate policies they had defined for their own reasons (as happened in the 1979 Dutch White Paper on Innovation, which I discussed in the introduction). Policy makers and managers are themselves part of the evolutionary process. Thus, versions of strong planning and command-and-control approaches, or the equally ideological neo-classical economists' approach of leaving everything to the market except for a few generic fiscal measures to overcome collective-good problems, must be evaluated in terms of their function in specific evolutionary processes. Already, with Nelson and Winter (1977), the 'selection environment' of their theory is much broader than the market and includes the patent system and other institutional configurations. Intervention in such broader configurations and their evolution is not a simple matter. As I intimated already, the general approach is to understand ongoing dynamics and try to modulate them – this includes joint-learning approaches.

A further reason to prefer an evolutionary theory of technological innovation is the fact that the success of an innovation does not just derive from the power of the technological option on which it is based. I will develop this point, drawing on the insights from studies of processes of technological innovation. This will enable me to present an evolutionary theory of technological change and innovation in three steps.

The first step is to consider the introduction of novelty into an existing order. The analysis provided by Abernathy & Clark (1985) is a useful entrance point but must be extended. They emphasize how existing linkages – with customers and in markets – are broken, and how existing competencies (technological and other relevant capabilities within the firm) become irrelevant ('obsolete' is their term). Such 'de-alignment' is accompanied by 're-alignment': the building up of new linkages and competencies. One can think of firms having to work with new suppliers and customers, and having to retrain personnel. 'Re-alignment' creates links with the selection environment and thus some fit but this remains precarious. There is no guarantee of success and, in that sense, the evolutionary notion of a partially independent selection environment continues to apply.

Abernathy & Clark focus on the firm and its immediate business environment. But in fact, and especially if one considers longer-term developments and broader notions of success than short-term profits of a firm, societal linkages and competencies are involved as well (Rip, 1995). New products can be taken up in other sectors; think of information and communication technologies as an important example. Analysts like Freeman and Soete (1997) have pointed out that the necessary 're-alignments' within and across sectors take a long time. For them, this explains the so-called productivity paradox (investments in the use of ICT are not yet reflected in increased productivity). Longer-term changes can add up to transitions, and the patterns in such transitions can be understood in terms of re-alignments and their partial stabilization (Geels, 2005).

Another element in societal linkages and competencies is domestication of new technologies, including issues of public acceptance. For biotechnology and genomics, these issues are important in many countries, and managers may consider adding 'societal embedment' to their product development strategies (Deuten et al., 1997). With the emergence of nanotechnology, scientists, industrialists and policy makers now anticipate such issues and develop activities to avoid or mitigate them (Rip, 2006b). My theoretical point is that the de-alignment that occurs with respect to existing sectors and their cultures, and is expected and now discussed at the level of society as well, is not a matter of undue reluctance, or even resistance, by publics but a general feature of technological change. If technology promoters seek to impose re-alignment without recognizing the

actual dynamics for what they are, their actions may well be counterproductive, as the impasse over agricultural ('green') biotechnology has shown.

In this first step, I have already gone further than the simple evolutionary approach of considering the introduction of novelty as a mutation or variation, and see selection mechanisms of various kinds as determining whether it survives and grows. In Nelson & Winter's theory and their subsequent model (Nelson and Winter, 1982), routines within firms to produce innovations are the retention mechanism (the third key component in any evolutionary explanation), and selection works on the firms in markets and other selection environments. Important also for my analysis is how Rip and Kemp (1998), and in a slightly different way Basalla (1988) and Levinthal (1998), have focused on new technological options rather than actual products, so that one can include the quasi-markets that have emerged for them (cf. Schaeffer, 1998) in the theory. This links up with earlier analyses of expectations and promises about new technological options (Van Lente, 1993; Van Lente & Rip, 1998), and recent studies as in Brown et al. (2000) and Borup et al. (2006).

This enables the next step in the theory, the recognition that variation is not random but shaped by anticipations, which can become stabilized as regimes or paradigms (Dosi, 1982). This links up with the phenomenon of dominant designs as, for example, the VHS video cassette recorder, which became dominant after a struggle with alternative, competing designs (Cusumano et al., 1997). Further innovation then occurs within the framework of the dominant design. Over time, the dominant design may shift or even be undermined and disappear. In the short run, innovations running counter to the dominant design and, more generally, to the rules of the dominant regime will be more difficult to realize, and they may well face barriers that are not easy to overcome.

These last observations indicate that the evolutionary perspective overlaps with what in general sociology is called institutionalization. Some novelties, at first precarious and surviving because of the promises claimed for them (up to the hype surrounding e-commerce, and now genomics and nanotechnology), will grow and become established – which is to say, they will become irreversible. Like institutions more generally, they will then resist further change. This occurs in the small, on the micro-level, as when organisations resist renewal from within or from without. But it also takes place in the

large, on the meso-level of dominant designs, industry structures and standards, and on the macro-level of techno-economic paradigms. See, for instance, how Freeman and Louçã (2001), in their analysis of long waves in the economy of modern societies, highlight the role and dynamics of structural readjustment.

The third step is to open up this picture of a tendency to stabilization and institutionalization, and to do so in two ways. There are broader developments that may unsettle stabilization. And there is the challenge of anticipation in an uncertain and largely unpredictable world. Actors develop ways to handle uncertainty – in evolutionary terms, by maintaining some variety and/or attempting to protect novelties against harsh selection. Other (often *de facto* or pattern) strategies are to reduce complexity by relying on shared expectations about future developments. Such shared expectations offer a sense of direction but that may be deceptive. A more sophisticated understanding of dynamics is important, starting with the recognition of non-linearity of developments.

Over time, there are shifts in functionalities and uses of an innovation, and there is uptake in other sectors, which induces further developments. The functions the telephone now fulfils are very different from the ones envisaged originally: business communication between the centre and the periphery of the town, and piping concerts from the concert hall in the city centre to the suburbs. Similarly, the idea of mobile telephony was raised as far back as the 1920s and led to prototypes, e.g. a motorcar with a radio, which allowed a link-up with receivers of the signal elsewhere – a far cry from present-day mobile telephony.

In other words, the strategies of managers – and, at one remove, policy makers – should not just be based on performance in present contexts, and actors' intentions and their predictions of eventual achievements. One way to do better is to develop scenarios that encompass non-linearity, for example, by drawing on a 'branching' model of technological development. Another way is to consider evolving contexts, i.e. shifts in the selection environments (markets and institutions), as part of the dynamics. This implies that one should speak of co-evolution rather than evolution. Nelson (1994) has already emphasized co-evolution of technology, industry structure and supporting institutions. We have used a broadly co-evolutionary approach to analyze and characterize processes where whole regimes were transformed, as from sailing ships to

steamships (Geels, 2005). An important feature of co-evolution is its multi-level characteristic, where sequences of events at the micro-level, institutions and industry structures at the meso-level, and macro-level changes have their own dynamics but also interact. Again, there is unpredictability, which confounds modernistic attempts at intervention to achieve a goal. Yet, understanding of the multi-level dynamics is important and scenarios can be drawn up, as we have shown in the case of nanotechnology (Rip & Te Kulve, 2008).

THE QUEST TO INTERVENE: INFLUENCING TECHNOLOGICAL DEVELOPMENTS AT AN EARLY STAGE

In the overall co-evolution of technology and society, a variety of actors are interested in influencing technological change from the perspective of their own goals. Firms will think in terms of market success and strategic advantages. NGOs have their values to pursue; for example, health improvement or a clean environment. National governments and other government agencies have overall goals such as security, quality of life and sustainability, under which a variety of actions are formulated and implemented. Their assessments of the situation, and their actions and interactions, contribute to the co-evolution.

Actors interested in intervening will do better – also in achieving their avowed goals – when they draw on an understanding of the co-evolutionary nature of the overall process. They will then give up on unproductive command-and-control approaches. I note that there are paradoxes: such reflexive action may change the nature of the co-evolutionary processes – so that earlier understanding of the overall process is no longer sufficient. The basic point remains that there is an advantage in understanding the nature of the processes that one is part of and is trying to modulate.

There is a particular challenge, not just for technology developers but increasingly for policy makers and critical societal groups as well: how to influence technological change at an early stage, when irreversibilities have not yet set in and when one can still hope to sway the balance between desirable and undesirable impacts – for oneself (as in

the case of the battle for an industry standard, e.g. video recording) or for society more generally.

One problem, clearly, is the difference between functionalities originally envisaged for a technology and the eventually dominant ones that emerge. The branching model, exemplified above in the case of telephony, tells you there will be branching but not which branches will emerge and become dominant. It sensitizes actors to the complexities and so may help to avoid unproductive action. Interestingly, actors learn from past experiences with the dynamics of technological change; for example, in the recent struggle for new DVD standards (Blu-ray vs. HD-DVD) where actors and media refer back to the earlier video-recording standards battle.[1]

Linked to the cognitive problem of not being able to predict the eventual shape of a technology and its context, there are two action-related dilemmas. The so-called anticipation dilemma refers to firms and other technology actors who might prefer to postpone action until the situation is clearer but cannot equivocate indefinitely (Verganti, 1999). For the societal level, where governments, NGOs or societal groups may want to influence technological developments to avoid or limit negative impacts, Collingridge (1980) formulated the knowledge-control dilemma. The dilemma is not unique to technological innovation in context but is readily apparent there: at an early stage, when technological developments are still fluid and amenable to some control, it is unclear what impacts will occur. By the time the first impacts become visible, there are so many irreversibilities, including vested interests, that it is impossible to effect changes for the better.

One can redefine (but not resolve) the dilemmas by recognizing that the dichotomy (especially in the knowledge-control dilemma) is artificial. There are ongoing developments in which assessments are made all the time, tentative steps are taken, and learning from these experiences occurs. As with Lindblom's incrementalist approach to policy (Lindblom and Woodhouse, 1993), there is no guarantee that the path that emerges is a 'good' path. Additional reflexive learning is important (even if it will not provide a guarantee). So-called Constructive Technology Assessment approaches support such

[1] *Financial Times* (26 August 2005) had an article headed: "Repeat of VHS versus Betamax conflict looms", and noted that "Mr. Nishida [Toshiba's new President] said that the two sides had not given up trying to agree a deal on technical standards, which would avoid a repeat of the video technology battle of the 1970s, when Sony's Betamax lost out to the VHS format."

reflexive learning, and they address the additional problem of the variety of actors and their possibly contrasting perspectives.[2]

Learning is fractured by the contrast between 'insiders' who invest in developing new technology, and 'outsiders' who receive the results, whether they like them or not. This is not just the general contrast between producers (of a new product) and consumers (with their own, partially articulated preferences). Especially in R&D-based innovations, the development trajectory optimises the new process or product *per se* but its eventual success requires re-contextualisation; a process that cannot be anticipated fully, let alone determined, at the earlier stages of the trajectory. A striking example is the negative reception by the deaf community of cochlear implants – because this technology undermined their culture (Reuzel, 2004). The 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 often a matter of insiders but will ultimately be exposed to outsiders). And it is not just a matter of myopia on the part of inside actors. There is a real dilemma because there are costs involved in taking wider contexts into account at an early stage.

Garud and Ahlstrom (1997), who discuss a number of such examples, draw attention to what they call 'bridging events' between insiders and outsiders. A similar point was made for the role of outsiders and of alternative products in attempts to change existing technical regimes (Van de Poel, 2000). The 'bridging events' might become institutionalized and then create a 'nexus' between the variation and selection components of the co-evolution of technology and society. The concept of 'nexus' was introduced by Van den Belt and Rip (1987) to show how test labs in the synthetic dye industry in the late 19th century were a way to anticipate on the selection environment. After a time, the dynamics were reversed, when dyers started to follow the instructions of the synthetic dye manufacturers. The concept of nexus can be applied more broadly to cover all types of institutionalised couplings between variation and selection.

These are general considerations. The key point to be drawn is that actors who understand co-evolutionary dynamics and emerging patterns can play on them to

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[2] Rip, Misa and Schot (1995) set out the general idea and Schot & Rip (1997) outline generic strategies, including Strategic Niche Management. There is now also 'real-time technology assessment' (Guston and Sarewitz, 2002).

modulate what happens and perhaps realize some of their goals – a modest modernism. I will show how this point can work out by focusing on a concrete and recurrent pattern: that of an innovation 'journey', as Van de Ven et al. (1999) use the notion. I will mobilize further findings from economics and the sociology of innovation to expand the use of the concept to include contexts and their changes. My analysis will, in a sense, be a demonstration of the possibility of identifying opportunities for intervention, based on an understanding of how the innovation journey is articulated over time, and how it can be mapped anticipatorily because of the existence of recurrent patterns.

THE INNOVATION JOURNEY

Van de Ven and his collaborators introduced the idea of an innovation journey for product and process development in industrial firms (and in networks including R&D institutes) to capture the fact that there are lots of contingencies, shifts and set-backs during the innovation process, and planning and management have only limited effect (Van de Ven et al., 1999). Actual developments were traced retrospectively in the Minnesota Studies on Innovation (Van de Ven, 1989) and used as an argument – as a mirror, as it were – for actors to recognize the complexities. The mapping of the complexity of a journey is necessary because 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. Although this is evolution – trial-and-error variation and selection dynamics – one can try to do better.

Conceptually, the innovation journey is a cross-section of the overall co-evolution, and one which has travelled following the enactors of innovation. Given the dominant role of enactors of innovation in determining what will happen, the recognition of overall patterns in such innovation journeys is important for other actors (governmental agencies, NGOs, societal groups) as well, when they want to exert some influence. Figure 1 assembles and integrates results of a large number of studies on industrial product and process innovation. The background of this particular methodology of mapping the innovation journey in context has been described elsewhere (Callon et al.,

1992, on techno-economic networks; Rip and Schot, 2002, building on that type of analysis).

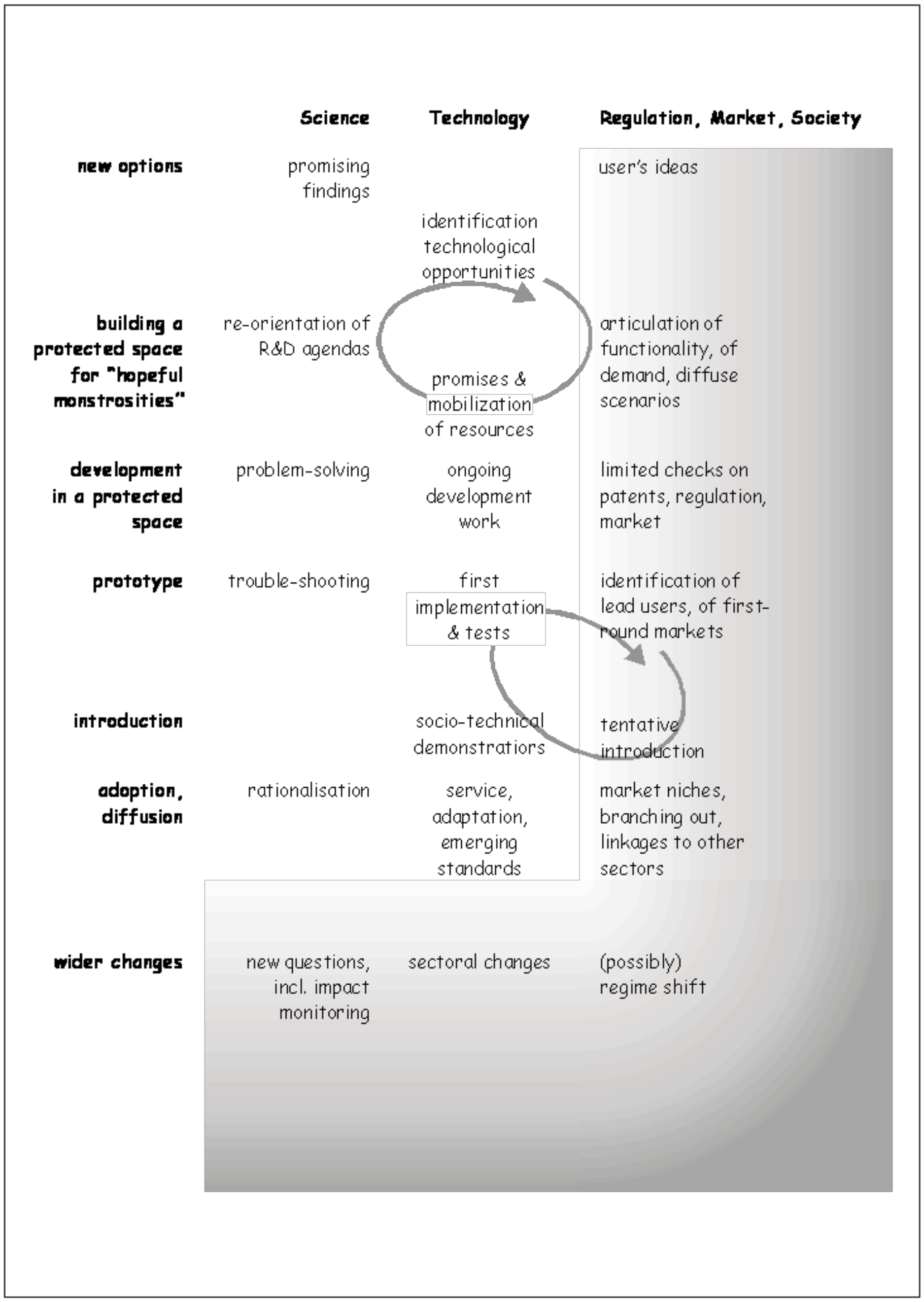

Figure 1: Mapping the Innovation Journey in Context (from Rip & Schot 2002)

Drawing heavily on Rip and Schot (2002), I will tell the 'story' of the innovation journey. It starts with the identification of an opportunity: a new technological option, or the pressure to find a solution to a problem. New options may derive from R&D findings or scientific advance in general but other sources remain important. The role of science varies but has often to do with the discovery or modification, in the laboratory, of an effect that is linked to potential applications (cf. also Robinson et al., 2007). Such discoveries are widely published and pursued in many places without necessarily leading to innovation journeys (Van Lente, 1993). An example is the discovery of high-temperature superconductivity, which led to speculation about more efficient magnetic trains (eventually, other applications of this new laboratory phenomenon proved to be more realistic, e.g. detection systems for very weak magnetic signals). New options can be actively sought, as in the pharmaceutical industry, where the search for 'leads' is a recognized activity. 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, functions – and thus, the search for opportunities – are articulated in a more *ad hoc* manner.

For my analysis, the key point is that such technological opportunities always start out as 'hopeful monstrosities': full of promise but not able to perform very well. Actors will make more specific promises (to internal and external sponsors) to mobilize resources to be able to work on the technological option 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. Since they also specify what the material, device or artefact should be able to do (its 'performance'), an R&D agenda will be identified and somewhat stabilized. A promise-requirement cycle is launched and shapes the trajectory of development (Van Lente & Rip, 1998).

There will be exaggeration and hand-waving claims, and actors can adopt different strategies: embrace hype or underplay the promise for fear of creating disappointments and a backlash. (This was clear in biotechnology and is occurring again in nanotechnology, cf. Rip, 2006b.) The net effect of the networking and resource mobilisation is the emergence of a protected space for promising R&D and developing the technological opportunity, inside an organisation or across organisations (for example, in the development of a military aircraft, Law and Callon, 1992). Part of the protection stems from a (precarious) agreement over a diffuse

scenario about functions to be fulfilled and their envisioned societal usage. The nature of the protected space, together with its boundary agreements, including the rules and heuristics derived from the promises that were made, 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). In Figure 1, this is visualized as a cycle, giving rise to temporary path dependency (cf. Garud & Karnoe, 2001).

The advantages of a protected space are clear. Such spaces can be consciously designed, up to the extreme version of a 'skunk works', as when IBM constituted a separate group, with its own resources and outside regular management control, to develop its PC. The risks derive from the fact that the diffuse scenario that legitimated the creation of the protected space in the first instance is not updated. This is related to the fact that, in the early stages, the market/society pole only figures in terms of market studies, early promises, and other expectations. Such expectations will 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). In general, the neglect of changes in the outside world can create problems later on, which require repair work and/or (unexpected) shifts in direction (Deuten & Rip, 2000). And, sometimes, the promise will turn out to be empty after all.

The second cycle indicated in Figure 1 also gives rise to some path dependency and thus another trajectory in the journey. At some moment in time, a decision is taken (or emerges) to go for prototypes or other attempts at demonstrating a working technology. Activities include exploring/optimizing production, with trouble shooting and rationalization through further research; implementation of the product and learning about usage, and preliminary market or demand testing. As in the case of biotechnology, regulation and acceptability can become real issues and might direct efforts in particular directions (as happened, for example, in genetic modification of corn and wheat with the choice of herbicide and pesticide resistance rather than of disease resistance).

These activities are much less self-contained than in the earlier research and development trajectory, and subject to more intra- and inter-organizational tensions. Thus, other interactions and management styles are called for. With the tentative introduction of the new product or process, with a few customers ('lead users'), or in a 'societal' experiment (and then often in collaboration with public authorities, as in the case of electric vehicles, cf.

Hoogma et al., 2002), the complexity increases but also the opportunities for real-world learning and subsequent modification of the product. Because specific socio-technical couplings are introduced, path dependencies may occur: when dedicated niches are created for learning, the kind of learning depends on the nature of these niches, and this may not be adequate to the demands and selections in the wider world. In addition, as the visibility of the project/the product increases, there may be reactions and repercussions.

Market introduction, an important concern for marketeers and for higher levels in a firm, is thus a process rather than a point decision. The 'market' is neither one-dimensional nor homogeneous, and demand is only gradually articulated in response to supply. There must be something like a protected space (a niche) for the new product, so that it will survive an otherwise too harsh selection, in general and because it might go against the dominant regime.[3] At the same time, when limited to the particular protected space, a product is created that can survive only within that space. This may well be the final outcome: a product for one (and limited) market niche. For a long time, fuel cells, in spite of their recognized general promise, functioned only in space applications. Because of shifts in the motor-car world, a 'branching' occurred and fuel cells are now adopted in earnest to drive motor cars.

By the time branching and wider embedding in society occurs, a third phase of the journey emerges. The dynamics depend on the sector and on wider developments, just as much as on the introduction and diffusion of the innovation itself. There is a cumulative effect of further varieties of application, of suppliers orienting themselves to the new technology, of economies of scale and scope that are exploited, and of recognition by users of further possibilities, which creates new socio-technical 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 is recognized as a pervasive technology and characteristic of a new techno-economic paradigm (Freeman & Soete, 1997).

[3] Every innovation that actually or potentially goes against a dominant regime will have difficulty in de-aligning existing linkages and ways of doing things, even when such alternatives have some credibility, for example, because of a promise of sustainability. Re-aligning requires room for experimentation and learning, which is not freely given. The general approach of Strategic Niche Management can be used (Kemp et al., 2001), even if one has to be careful and avoid a simplistic David *versus* Goliath storyline: the tiny novelty conquering the mighty regime (Stuiver 2008). As Hoogma (2000) has shown in the case of electric vehicles, a partial 'fit' strategy is often the only possibility at an early stage and, only after some niches have been created, can the more ambitious 'stretch' strategy be successful (if at all).

Cumulative effects may 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. Of course, actors will attempt to do so; they will jockey for position in the newly emerging games and regimes, and involve themselves in strategic alliances. In standard setting in information and communication technology and in consumer electronics, such processes are very visible. These then become part of broader socio-technical regime changes. One can argue that a third 'cycle' can result from regime change, when further developments are shaped by the 'grammar' of the new regime. In fact, a number of authors have analysed historical cases in these terms (Van den Ende & Kemp (1999) on the computer regime, and Geels (2005) on steamships, motorcars, and jet engines). Regime change and its stabilization can be presented as a victory. Indeed, the actors involved, as well as the media reporting of the struggles, may think in terms of heroic stories in which power and cleverness of (single) actors determine the outcome. While there definitely is a role for 'regime entrepreneurs', the cumulative process of increasing interdependencies and sunk investments is decisive.[4]

In this stylized description of the innovation journey, three clusters of activities can be distinguished where the innovation journey enters a new phase, and a trajectory with its own dynamics is launched:

- build-up of a protected space,
- stepping out into the wider world,
- sector-level changes.

Each phase has its own dynamics and the trajectories are not easy to modify. But, before the path 'gells', it is easier to exert influence while there is also some assurance that a real difference will result because the intended shift becomes part of the trajectory. In other words, attempts to influence the innovation journey – i.e. to help shape its further evolution – should focus on the entering of a new phase as the *locus* where a difference can be made (Rip & Schot, 2002). This is a way to address the dilemmas of Verganti and Collingridge with which this section opened.

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[4] Compare how Garud et al. (2007) speak of (socially) embedded entrepreneurs.

DISCUSSION: INTELLIGENT INTERVENTION IN INNOVATION JOURNEYS

Making a difference is not a matter of brute force but of intelligent intervention – i.e. playing with the dynamics and drawing on a sophisticated understanding of them. This applies to attempts at intervention by insiders as well as outsiders. 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. Also, waiting games may emerge, which create impasses even when there is a sense of direction.

A 'shadow of authority' may be necessary to break through impasses. Credibility pressures, for example in relation to environmentally-friendly products and processes, can also 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 because of the outsider position.

Governmental and societal actors face the further problem of evaluating the dynamics and possible directions of an innovation journey (often, a cluster of innovation journeys – say, in the genetic modification of plants) from the outside and relating them to their own (often not completely articulated) views of what is desirable. Such views can relate to wealth creation, policy learning and/or risk avoidance, and there may well be conflicts between the various views and goals. The key point is that not only the eventual performance, uptake and use of the new technology and products but also the views and preferences related to the new possibilities are unknown at first. In other words, Collingridge's knowledge and control dilemma is actually a trilemma, with the third horn related to uncertainty about desirable directions. The third horn can be turned into an opportunity for policy articulation and engagement with civil society, as has actually been proposed by a European Union Expert Group looking at the challenges of converging technologies (Nordmann et al., 2004). The strategy articulation workshops that we have designed and organized, focusing on domains of nanotechnology and their contexts, are also

an occasion – in the small – of addressing the third horn of the Collingridge trilemma (Van Merkerk & Robinson. 2006; Robinson & Propp, 2008; Rip & Te Kulve, 2008).

Here too, understanding the dynamics of developments is necessary to arrive at adequate insights and realistic action. This leads to the further question of the robustness of the co-evolutionary perspective and, in particular, the approach employing innovation journeys, as laid out in the previous section. There are two basic points that must be addressed: how to turn essentially retrospective insights concerning what happens in innovation journeys into prospective suggestions for action. And how generalizable is the pattern of the innovation journey as summarized in Figure 1.

First, the mapping of innovation journeys, as carried out by Van de Ven et al. and in our own case studies of nanotechnology domains, and also in the many historical, sociological and economic case studies of innovation, is essentially retrospective. It shows what we know about such processes as they have occurred. In the beginning, however, only the items at the top of the map (Figure 1) are in place, and the future is uncertain. Over time, when the innovation journey progresses, further parts of the pattern shown on the map materialize. At an early stage, actors will rely on their own projections of how innovation processes usually go, and what is necessary to make them successful, to guide them in their actions. Things might still go wrong, of course, and for a variety of reasons. One cluster of reasons is the limitations of actors' views: because of their limited experience, because of a tendency to be myopic (which can be reinforced by the context, cf. Pavitt, 1990), and because of neglect of what is already known. Thus, having an overall map of the general pattern in the innovation journey (if and when relevant to their situation) will help them to do better.

This 'enlightenment' model applies to all actors: technology developers or 'enactors' (Garud & Ahlstrom, 1997), policy makers and other government actors, 'third parties' such as venture capitalists and insurance companies, and civil society actors. We have been involved in developing mapping tools to support 'enactors' of innovation, which introduce complexity (in particular, by forcing actors to specify the context of the innovation and taking it into account) and thus enable them to do better.[5] The key

[5] The tools range from translating insights from economics and the sociology of technology (Rip 1995), and visualizations of concentric biases (Deuten et al. 1997), to more detailed project management support in the SocRobust

element that justifies a knowledge-and-understanding-based prospective approach (in contrast to brainstorming about the future) is the notion of 'endogenous futures' (Rip et al., 2007, Rip & Te Kulve, 2008). Co-evolutionary dynamics do not stop in the present where actors consider their actions as if they were free agents. In other words, futures are predicated on what has been happening. Our understanding of such co-evolutionary dynamics is sufficiently advanced to articulate what such futures might be. In the case of path dependencies, leading to trajectories, this point is widely recognized. Broadening the notion of path dependence to 'entanglements' (Rip et al., 2007) allows further application of the general idea, even if the prospective mapping should not be linear (that is a reason to work with scenarios). The innovation journey pattern, as discussed in the previous section, can now be seen as a way of recognizing, at an early stage, endogenous futures.

Second, the question of generalizability of the pattern. My analysis of possibilities for modulating an innovation journey was carried out for a quite specific context: that of technological developments initiated in firms or other technology-promoting organizations. In other contexts, we might find other dynamics. This need not undermine the general suggestion of intelligent intervention focused on specific *loci* but their specification, and the shape of the intervention, will have to be different.

Further, I am prepared to claim that there are only a limited number of different patterns in innovation journeys. My argument for this claim is contextual. The reason the innovation journey for industrial product and process innovations has a recognizable and recurrent pattern is the way industrial innovation has become institutionalized in our societies. The pattern is reproduced because it is seen as the natural way to do things and because it remains productive. Other patterns that might occur will also depend on the nature of the innovations and the nature and extent of institutionalization, and that is how we can identify them.

I will discuss innovation in agriculture, taken to include nature and rural development. The general features of innovation, such as the introduction of novelty and the de-alignment and re-alignment that occurs and has to occur, will be visible there as well. A specific feature is how natural processes in the soil, in plants and in animals and their interactions, are an

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project, where we offered ways to draw managers out of their concentric bias (Larédo et al. 2002). Our recent scenario exercises (Rip and Te Kulve 2008) are a further step.

integral part of the configuration that has to work. 'Natural history' is more important than mechanical and electrical engineering, and design and construction take on a different complexion. Natural processes are variable and locally contingent, so that what works on a particular location and at a particular time may not work elsewhere and at another time. And one has to wait and see what grows; one cannot simply force one's intended re-alignments on nature.

Thus, while protected spaces for further development such as field experiments are possible, they will not always deliver results that are transferable to other fields – unless these can be transformed so as to be identical to the original field of the experiment. While nature is always a partner in the co-production of innovation and its impacts, there are different ways of 'managing' the partnership. One route is based on experiments in laboratories and agricultural stations (so the protected spaces are more or less controlled), and novel options need to be transferred, precariously, to local practices. This is mostly done by colonizing these practices and transforming them into something similar to the experimental plots (the traditional route of agricultural research and extension since the late 19^{th} century). There is increasing interest in another route, that of modifying the new option rather than modifying the local practice, because of the failures that occurred in the later route (Wiskerke & Van der Ploeg, 2004). Recognizing this, one can start at the other side with novelties generated in local practices and consider that as the basic pattern. The currently dominant expert-based regime would then be seen as an overlay on the basic pattern (Van der Ploeg, 2003), and its failures – for example, the grinding down of the Green Revolution – would be seen (and explained) as structural because of the neglect of the basic 'natural history' pattern (and of social dynamics).

The basic pattern is still alive, even if it has to survive in a modernist world. Local novelties will confront a dominant regime not only in terms of how to justify and develop themselves but also in relation to rules and regulations derived from the dominant regime. An example is how new ventures in low-input agriculture, including new ways of handling manure (in Friesland, one of the Dutch provinces), had to struggle against regulations specifying how ammonia emissions should be reduced. It took network building and concerted action to gain exemption from the regulation and demonstrate the promise of the new approach (Stuiver, 2008). A protected space was created for further experimentation but it was geared to the contingencies of local situations and their history rather than controlled

construction and performance measurements, as in the industrial product development pattern. As case studies in South Africa have shown, novelties need to be protected against the traditions and exigencies of the local situation to allow them to grow – and an additional ambivalence is introduced by the role of sponsors and donors creating such a protected space, which also implies dependency relationships that cannot always be overcome (Adey, 2007).

Modern agriculture (including nature and rural development) is in flux, and patterns that were common before the Western expert-based regime asserted itself, in the West and then elsewhere, are accepted again. This is also visible in the debates on (and contestation of) high-tech inputs in agriculture, where participatory approaches and integration of local knowledge are increasingly welcomed.

If one looks at innovation in agricultural machinery and agro-chemicals, and now biotechnology, one will see innovation journeys resembling the pattern of industrial product development. However, if one starts with local practices – or just with the difficulties of handling natural variability and contingency to serve human purposes – another pattern is visible, where innovation on location, including social innovation, is the driver. The expert-based and high-tech routes are an addition to this pattern. Actually, when one looks closely, there are many interesting cases where the ultimately successful innovation consists of local practices developing endogenous technology together with selective use of imported technology (Bertelsen & Müller, 2003).

It is possible to identify and explore patterns of innovation journeys in other domains. Concretely (and realizing that I am reducing actual complexity), I suggest there are four main types of innovation journey, their differences depending on the institutionalisation of innovation in various sectors and their historically evolved constellation of actors, and on the nature of the relevant technologies-in-context. One reason why constellations of actors are important is their role in creating protected spaces.

The four basic types of innovation journey are:

1. industrial product and process innovation, where firms recognize that dedicated effort is necessary rather than just learning from practices.

2. energy, transport and infrastructure, where long lead times are taken into account, and there is little or no possibility of testing the overall system in a protected space. The real world becomes the laboratory (cf. Krohn & Weyer, 1994).
3. ICT, with its dual structure (carriers and services), big and small players, and the key role of software engineering and orgware and socioware aspects.
4. 'natural history' as exemplified in agriculture (and nature conservation, environment, and rural development) but also in medical practices.

There are overlaps and mixed dynamics, as was clear in the case of agriculture. Transitions towards, for example, a hydrogen economy follow Pattern 2 but are enabled by Pattern 1 innovation journeys as in fuel cells and hydrogen storage devices. The medical and health domain is such a mixed-dynamics case, I would claim, so that it would not qualify as a further basic type of innovation journey. Earlier practice-based innovation patterns in this domain were backgrounded by suppliers of apparatus and drugs, even when the role of professional users remained important (Blume, 1992). While Pattern 1 may now be dominant, the increasing importance of health care is the reason that the practice orientation is coming back. The overall pattern may well become like the one for agriculture – handling variability and local contingency of natural processes, now of humans rather than soil, plants and animals.

Of course, each of the types of innovation journey can (and should) be described in as much detail as I provided for the first industrial product and process innovation, and as I started out to do for agriculture. For intervention, the key point is to forget about one-size-fits-all approaches and recognize that innovation patterns can and should be disaggregated to be able to address ('manage') them productively. Pavitt (1984)'s early analysis of 'innovation patterns' has the same thrust but he refers to largely stabilized industry structures rather than to the dynamics of innovation processes.[6]

Clearly, there are recurrent patterns in the co-evolution of innovation, institutions and society. Going for modulation rather than command-and-control, there are still

[6] Van de Poel (1998) introduced a (necessary) modification to Pavitt's typology by including a mission-driven pattern where the role of government is important. There is also the extension of the typology to services, as in the often quoted paper by Soete and Miozzo (1989). Unfortunately, within the scope of this chapter, I cannot address innovation in services explicitly.

varieties of modulation. Taking one pattern as the entrance point, the innovation journey in the context of industrial product development allowed me to identify interesting possibilities for modulation: *loci* for making a difference, protected spaces and strategic opening of such spaces. Additional research and further reflection is necessary, especially to discover if the overall approach of looking at dynamics and ways to modulate the dynamics can be productively applied to energy/infrastructure and ICT.

CODA

I have come a long way since 1977 when the Nelson & Winter article was published and some governments adopted their message in their technology and innovation policy. In a sense, innovation has come a long way as well. To paraphrase the title of a chapter in Felt and Wynne (2007), innovation has been reinventing itself including, on the one hand, open innovation around promising high tech (cf. journey type 1) and, on the other hand, 'collective experimentation' as in open-source software (cf. journey type 3), and the involvement of patient associations and farmers' collectives (cf. journey type 4). Other authors like Von Hippel (2005) and Malerba (2006) have indicated changes in innovation patterns (for innovation journeys type 1 and type 3). For the type 2 innovation journey, long-term planning and coordination, now with public-private alliances (and a neo-corporatist governance pattern), continues.

Another important change is the interest in anticipatory coordination in the face of uncertainties about new developments. The advent of European Technology Platforms for particular areas is a strong indicator. While they are established for all sorts of domains, there is an emphasis on capturing promising high-tech domains such as nanotechnology, embedded systems and the hydrogen economy (and their innovation journey type 1 dynamics). Such anticipatory coordination adds to the reflexivity of co-evolution. When there are effects, it will be through modulation, and this then becomes an integral part of 'doing' innovation. It is a further example of institutionalized coupling between variation and selection, i.e. a nexus.

So what is the role of government? The basic point that government is only one of the actors in the overall evolution of multi-actor, multi-level systems and their interactions is increasingly recognized. Government does have a special responsibility: for infrastructures and other collective goods, and for the conditions that allow for productive and desirable innovations. Implementing that responsibility through generic measures, as neo-classical economy would suggest, runs up against actual variety. Specific measures will, of course, suffer from information asymmetries. The problem (a dilemma?) can never be resolved completely but the reduction of complexity that I have proposed, of thinking and acting in terms of a limited number of patterns of innovation journeys, will go some way to addressing that problem.

The traditional justification for government technology and innovation policy was market failure. There is government failure as well. In a co-evolutionary perspective, the important issue is selection-environment failure and the need to address such failures at the system level (Smits & Kuhlmann, 2004), where government has a role to play anyway. Stimulating nexuses and some monitoring of their productivity would be a new approach; or better, it occurred already but is now recognized for what it can do and why. An example is the establishment of Technology Assessment organizations as a link to selection environments through anticipation and interaction.[7] The recurrent discussions of patenting and intellectual property rights could also usefully be seen as being about the productivity of nexuses. Stimulating horizontal interactions between different kinds of actors, for a purpose, could also be designed and evaluated in terms of co-evolution, including the way government agencies are increasingly part of the consortia and forums that are formed.

These brief considerations should be located in the general thrust of my argument about understanding and intervention. There are patterns and dynamics to base policies and actions on, even if these patterns are contingent in the sense that they are outcomes of historical co-evolutionary processes. Modulation is what intelligent intervention should be about, by government actors or any other actor.

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[7] Freeman and Soete (1997), in their conclusion, put up a similar argument and suggest that government technology policy should limit itself to Constructive TA.

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