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In a multi-level perspective, regimes can be clearly described as long as they remain stable. To understand how regimes and niches interact during transition, the article contrasts two models of regimes in transition(s). The classical model of evolutionary niches suggests misalignments between rules and competition between niches. Transition management, technological innovation systems and works on transition pathways suggest a second model based on "unlocking rules", which support collective work on a structured set of emerging technologies. The latter model is illustrated with a case study on the International Technology Roadmap for Semiconductors (ITRS).

Keywords: socio-technical regime, transition, strategic niche management, unlocking rules

Introduction

This paper deals with transitions in socio-technical regimes and the nature of regimes when they are in transition. In a multi-level perspective (Geels 2004; Kemp *et al.* 1998; Nill and Kemp 2009), transitions from one socio-technical regime to another can be explained by the interplay of stabilizing mechanisms at the regime level and (regime-) destabilizing pressure of new societal needs (at the landscape level), combined with the emergence of radical innovation at the niche level. This multi-level framework accounts for some historical transitions (eg (Geels 2002; 2005)) and for a specific form of policy for socio-technical regime transitions: strategic niche management (SNM). SNM advocates the creation of socio-technical experiments in niches to facilitate the incubation process of the new technology while being protected from the constraints of the dominant regime. However, some authors have underlined that SNM as a change strategy can have a limited impact (Caniëls and Romijn 2008; Nill and Kemp 2009). A "good" niche has to meet such demanding conditions (good choice of technology, experiment, market diffusion strategy, etc.) that in many cases, the niches are not capable of changing the socio-technical regime (Caniëls and Romijn 2008; Smith *et al.* 2005).

Along similar lines, it has been suggested (Markard and Truffer 2008) that although it is indeed important to understand what happens at the niche level, it is also critical to understand what happens beyond that level, at the meso-level. At this level niches compete (Geels 2002) but also combine or aggregate (Geels 2005) and complementary effects of developments in different niches appear (Nill and Kemp 2009). Few studies have been done at this level (Genus and Coles 2008) creating a major gap in the literature. To address this gap, we investigate the management of a set of niches, at the meso-level of the regime, whilst the regime is in transition. *But, first of all, how can we characterize regimes in transition?*

In the model of transition in socio-technical regimes (Geels 2004), the regime in transition is described as a stable combination of rules, actors and technical systems that competes with niches where the regime rules are loosened (Geels 2002). However, this model leaves several open questions regarding the relationship, during the transition, between the regime level and the niches. Is the incumbent regime simply competing with the niches or is it able to interact and hybridize with them to mutate into a new regime? Are there alternatives to the evolutionary model?

To study these alternative models, in the first section we use the complementary perspectives of transition management and technological systems of innovation, which have studied situations where transition is managed *at the regime level*. In this situation, the logic of management has generated specific rules for the transition (Kemp *et al.* 2007). Contrary to the evolutionary model where rules are loosened, weakened and then substituted by a new and more robust set of rules, in transition management and with technological systems of innovations, *there are rules to support the transition*. Our research question is: what are these rules, which do not lock new paths but create them? In cases where there are such rules, who are the actors and what kind of technical system can be associated with them?

In the second section, we show that the literature helps to characterize an alternative model for regimes in transition that relies on rules at the regime level, which we call "unlocking rules". We illustrate this with a case study of how the International Technology Roadmap for Semiconductors supports regular transitions in the semiconductor regime (third section). This illustration helps us analyse other facets of a regime with unlocking rules at the regime level: i) at this level, actors and rules deal with the ecology of concepts of technical systems that can be imagined by the actors at a certain point in time (and not only with the existing system); ii) the actors coordinate and work together on these concepts in a specific collaborative setting, which we call a "college of the unknown" (fourth section).

Models of regime in transition

Transition management and technological systems of innovation provide insights into alternative features of the evolutionary approach to technical change.

The logic of unlocking rules

(Carlsson and Stankiewicz 1995) conceptualized a "technological system of innovation as an entity that creates novelties and supports established technologies at the same time." They interpreted both the technological system and the sectoral system of innovation concept, which includes an *innovation element* that creates, diffuses and uses new products (or technologies) and a *production element*, which is "responsible" for established products (or technologies). The latter is responsible for incremental innovation (and could be assimilated into a stable socio-technical regime); the former is responsible for radical innovation, which can lead to significant transformations. Fundamentally, this analysis considers a system that integrates a capacity to innovate, both incremental and radical. It is a meso-level approach that reaches well beyond niche level processes (Markard and Truffer 2008) and can help to analyse the regime in transition.

In this perspective, a main input of technological systems of innovation is the notion of structural and functional analysis (Bergek *et al.* 2008; Hekkert *et al.* 2007), which helped identify several sub-functions assigned to innovation systems: the generation and diffusion of knowledge, the guidance of search process, the creation of markets, entrepreneurial experimentation, legitimization, etc. They can be seen as *rules leading to radical innovation*. Instead of leading to path dependency, *these rules tend to create paths*.

Transition management has also pinpointed rules for the generation of radically new technologies. It is a model for managing transitions (Kemp *et al.* 2007) that includes the meso-level for a regime in transition. As a management model, it relies on rules and principles: long-term thinking as a framework for short-term action, thinking in terms of multiple domains, a focus on learning and learning about a variety of options and adaptive portfolios. This is not "intelligence" for planning, but an organized, stimulated Darwinist process of variation and selection. Once again, we find rules that do not lead to path dependency but, on the contrary, are formulated to overcome it. For instance, these rules counterbalance firms' tendency to have restricted technological horizons and bounded visions (Rosenberg 1976), thus avoiding technologies with long development times. Whereas the rules identified in stabilized regimes tend to lock into a dominant design, these rules unlock by aiming to create new design paths.

Let's begin by analyzing the rules that unlock *cognitively*. With Nelson and Winter's approach (Nelson and Winter 1977), a technological regime is defined as "the rule-set or grammar that is characteristic for the development of a technology and that guides not only the search activity of engineers, but also the actions and interactions of the other actors involved in technical development." Nelson and Winter gave the example of DC3 aircraft in the 30s, which defined a particular technological regime: metal skin, low wing, piston powered planes. The rules stabilize a representation of the object, of the functional target and the way to reach it. They lock potential paths by determining a technological trajectory.

By contrast, certain rules can create paths. For instance, the rules invented and taught at the Bauhaus design schools by famous teachers such as Klee, Itten and Kandinsky unlocked cognitive paths. Itten's course was an archetypal example of unlocking rules in art (Itten 1975) (Klee 1966): the laws of form, colour and shape helped students to disentangle too self-evident relationships between material-shape-colour-emotion and enabled them to explore beyond the clichés ("a warm fibrous wood"). We know the effects in term of generativity (famous objects, new grammars of forms, etc.). In engineering too, it has recently been shown that design theories and methods gain in generativity over time (Hatchuel *et al.* 2011). The generative power results from the rules set by the new design theories, which increase the capacity to rigorously use more diverse types of knowledge and to consciously break away from technological routines. These theories propose unlocking rules, to be embedded in the design reasoning. They can be as simple as: "in the case of an alternative between two solutions, design a third one." They can be rules to inhibit the reuse of locking rules (eg rules to formulate design briefs such as "an aircraft without a piston engine"; "wood is not necessarily fibrous"; or "agriculture is not necessarily unsustainable") or to encourage the opening of new ones ("an aircraft with fuel cells").

In the logic of socio-technical regimes, rules are extended to include socio-technical aspects (Kemp *et al.* 1998). Geels suggested that two other forms of rules be analyzed: regulative rules, ie explicit formal rules, which constrain behaviour and regulate interaction (eg government regulation) and normative rules, which confer values, norms, expectations and responsibilities and are internalized through socialisation processes (Geels 2004) (p. 904). Are there normative and regulative unlocking rules?

Normative unlocking rules can be seen in artistic milieus, where provocative, critical, inspiring comments are welcome and considered the relevant social behaviour. Here too, the example of Bauhaus provides interesting normative rules: students were encouraged to work together, to cross-evaluate their works and provide each other with constructive criticism (Droste 2002), ie to inspire, stimulate and educate each other, as a means of providing the mutual enrichment and development of the individuals involved. In innovation management, innovation teams and innovative firms have been described as using organic ways of acting together, which can be seen as normative unlocking rules (Burns and Stalker 1961; Le Masson *et al.* 2010; O'Connor 2008) since people are required to rapidly change the targets of the projects, to demonstrate radical innovation and to involve other stakeholders in their projects. In transition management, rules such as "societal experiments as bottom-up experiments" call for interaction in a way that unlocks the process. Normative locking rules are caused by social groups and support their stability. There are also rules that are caused by groups and which are *likely to change the group, the individuals and the objects* they are used to dealing with. In this sense, they are normative unlocking rules.

There are also regulative unlocking rules. Voluntary agreements (Aggeri 1999) are an example of regulative rules at the European level, intended to give stakeholders the incentive to create new paths. Regulative rules can unlock, in the sense that they facilitate the emergence of alternatives (instead of configuring a regime towards a given path).

Transition management and technological innovation systems suggest that in certain cases of regimes in transition, some rules at the regime level unlock rather than lock. Locking and unlocking rules can be compared as follows: i) unlocking rules tend to break dominant design rules, whereas locking rules tend to stabilize one path; ii) unlocking rules are open-ended (increase the variety of potential paths), whereas locking rules are deterministic (decrease uncertainty). Note that unlocking rules are not a weakened form of locking rules. Works on regimes and dominant design have underlined that (locking) rules can be strong or weak and that they can constrain (to follow a framework) as well as enable (inside this framework). Unlocking rules are not necessarily enabling, as they can also be either strongly or weakly unkocking. They can constrain and enable the breaking of the dominant design rules and the generation of new paths.

The logic of actors and systems with unlocking rules

We have clarified a type of rule that can exist in some regimes in transition. Are there forms of actors and forms of "systems" that are consistent with such centrifugal forces?

Once again, transition management literature provides some insights. It analyzes the logic of "systems" and actors at the meso-level of a regime in transition and shows that it requires "special innovation platforms and support for selected paths" (Nill and Kemp 2009); the actors should be able to coordinate their actions in order to adjust the exploration to take into account the learning acquired in all the niches. It is a model of governance for shaping processes of co-evolution using visions, transitions, experiments and cycles of learning and adaptation. The actors do not compete with one another, as described in the evolutionary process, but are required to work closely together, although not all the aspects of the technologies are known. They collaborate in the unknown.

Technical systems in transition at the regime level must be described differently. (Geels 2005) underlined the role of combination and aggregation between niches. (Nill and Kemp 2009) recommended that various transition paths should be explored, to avoid lock-in to a particular path. Analyzing the development of infant industries (Caniëls and Romijn 2008) underlined the role of complementary developments in providing inputs or consuming outputs of a technology. In such situations, the borders of the system cannot be limited to the past regime but have to include the emerging technologies experimented in niches.

To conclude, the logic of unlocking rules helps identify an alternative to the evolutionary model of regimes in transition. In the latter, niches compete and follow an evolutionary path that enables some of them to become a new regime, which may replace the incumbent one. Unlocking rules suggest an interactive, generative model, in which the regime in transition takes part in the emergence of niches and evolves in close interaction with them, before finally being transformed into a new regime. A synthetic comparison is proposed below.

	Model 1: evolutionary, substitutive	Model 2: generative, interactive
Interaction between niches and the regime	The weakened regime is replaced by a winning niche	The regime contributes to the emergence of niches and is transformed into a new regime through synergies and hybridizations
Rules	Locking: stabilizes one path, reduces uncertainty	Unlocking: inhibits lock-in, generates multiple paths.
Actors	Individual entrepreneurs with their own strategy	Collaboration in the unknown
System	A weakened system is replaced by one stemming from a niche	Actors work on the incumbent system and on the alternatives in niches

Table 1: two models of regimes in transition(s)

Case study: the International Technology Roadmap for Semiconductors

The logic of unlocking rules and the associated model of regimes in transition can be illustrated with the case of an industry roadmap, the International Technology Roadmap for Semiconductors (ITRS). ITRS intervenes at the meso-level of the semiconductor development regime. All the industry's major players (integrators, suppliers, universities, customers) use the ITRS to discuss and work together on the future technological generations (from +2 to +15 years). We used historical published and unpublished raw data from the ITRS and incorporated the key material gathered by (Schaller 2004). We added to this historical material thanks to our own deep involvement in the ITRS process. One of the authors of this paper has attended 11 face-to-face meetings and over 25 conference calls of the ITRS International Roadmap Committee (IRC) since 2005 and has had access to working documents from several of the ITRS' specialized working groups. He has conducted in-depth interviews with most IRC members, with experts in many of the ITRS working groups (2 to 5 people in five special interest groups – one on photolithography, three on device architecture, one on materials) and with researchers in research labs in the US (in particular Stanford Nanoelectronic Group and Stanford Nanofabrication Facility, 6 interviews) and in Europe (LETI in France, 8 interviews).

We analyze the following three key aspects of the case: first, we check for case relevance by showing why ITRS is at the meso-level of a regime in transition(s); second, we describe the relationship between the incumbent regime and the niches; third, we focus on micro-processes inside this meso-level. In this way, we gradually bring to light the unlocking rules found in a regime in transition, and the actors and systems related to this kind of rule.

Case relevance: ITRS and the meso-level of a regime in transition(s).

We check that the semiconductor industry can be considered as a regime in transition. First, it shows a priori all the features of a regime: there are complex systems with many interdependencies, high sunk investments, complex actor networks, high sunk costs in R&D, specialized top-level expertise in very specific domains, etc.

Second, we find the expected pattern of tensions and niches:

- Tensions: for more than a decade and for each new generation, engineers and scientists consider that the next generation will have to overcome critical bottlenecks with breakthrough technologies. Customer needs are changing; new businesses and functions are emerging regularly (RF filters, camera sensors, gyroscopes for smartphones and gaming, electronics for touch screens, etc.).
- There are also a large number of niches in the semiconductor industry: each actor (integrator, supplier, R&D lab, etc.) regularly creates original prototypes to be developed further.

Third, there have been changes in the regime – not only once, but regularly over several decades. On the face of it, the regime is governed by Moore’s law whereby technologies are designed to be able to exponentially increase the number of components incorporated per integrated circuit by regular dimensional scaling. However, Moore’s law has actually been responsible for multiple regime changes. For instance, it caused the emergence of new technologies and breakthrough architectural solutions, as in the case of photolithography for the semiconductor industry (Henderson and Clark 1990) or the use of new materials (in the last decade, the semiconductor industry, which was initially limited to silicon, has explored almost all the elements in the periodic table). Moore’s law has also regularly changed the relationship between actors because, for each generation, there are always several ways of designing the whole system, so that the individual technology suppliers have always faced open-ended questions in terms of the performances they have to achieve in the system.

Moore’s law can be seen as an unlocking rule as it obliges the actors to regularly open new technological paths. Contrary to the case of DC3, Moore’s law constantly sets new technological challenges (see below) as well as market challenges (eg by inventing new uses for computer power (Gawer and Henderson 2007)).

In this context, ITRS has a clear objective, defined since 1994 as follows: “The Roadmap is analogous to paved roads of proven technology, unimproved roads of alternative technologies, footpaths towards new technologies, and innovative trails yet to be blazed.” (Semiconductor Industry Association 1994). Right from the start, it was therefore clearly the intention of ITRS’ proponents to tackle changes in the technological regime.

Nonetheless, the ITRS is not a niche:

- it has lived through several regime shifts (the ITRS effort was first initiated at the US national level in 1993);
- it encompasses almost all the industry’s players in all geographic areas: its International Technology Working Groups (ITWG) address almost all aspects of semiconductors (design, process, instruments, etc.) and are composed of

experts from industry (chip-makers (50% of the members) and their equipment and materials suppliers (25%), research institutes (20%) and government agencies (5%)). The overall coordination of the ITRS process is the responsibility of the International Roadmap Committee (IRC), which has two to four members from each sponsoring region (Europe, Japan, Korea, Taiwan and the United States).

- ITRS' audience is very large: the great majority of the research programs in the leading institutions we visited are explicitly related to ITRS roadblocks.
- ITWGs do not carry out experiments: the members do experiments in their companies or labs, or report on experiments made elsewhere.

Hence, the ITWGs are not niches but they report on and stimulate niche activities. ITWG members meet on a regular basis, most often organizing side-meetings while attending scientific conferences in their field. In addition, general ITRS meetings are held three times a year and are an opportunity for the IRC and all the ITWGs to get together to share information about the general direction of their work, solve pending issues and have cross-ITWG discussions, thereby ensuring overall coordination. The ITRS report is released annually.

Hence, we can say that the semiconductor industry is a case of a regime in repeated transitions and that the ITRS is at the meso-level. We can already identify a logic of unlocking rules, eg the initial mission of the ITRS and Moore's Law.

Unlocking rules for managing niches at the meso-level

How does the ITRS manage the interaction between the regime and the niches?

Revealing and sharing the challenges

The niches are first managed at the level of the Overall Roadmap Technology Characteristics (ORTC), a series of tables providing a consolidated summary of the key performance targets for various product lines (DRAM, Flash memory, microprocessor). *They are not the result of existing technologies but a set of targets for designing future technologies capable of following Moore's Law.*

By identifying the targets that have not been reached yet or that have proved to be out of reach with the existing technologies, ITRS helps reveal and share challenges at the industry level. It provides targets to be met by future niches.

Monitoring and supporting niche expansion

ITWGs translate these ORTC targets into more specific ones and identify potential solutions.

We can illustrate this by studying how an ITWG managed the emergence of a radical technology. As the dimensions of transistors continue to shrink, new physical effects arise, such as "gate leakage" due to the onset of a tunnelling effect through the gate oxide layer. The need for new gate dielectrics was identified by the ITRS as early as 1994, calling for new technological developments. A first solution was mentioned in 1997 and led to a more precise description of the technological niche for this issue.

Several niches were then monitored in the reports, with regular analysis of their likely performance and date of availability (a first breakthrough technology was launched in 2009). If we take a closer look at the monitoring process, we can see that target performance levels evolved considerably for two reasons:

- As knowledge accumulated, it became possible to set more *precise* schedules and *more relevant* performance levels.

- The quantitative evolutions were linked to the discovery of what was attainable in the technological path in question but also to the evolutions in other, complementary, technologies. For each challenge, the industry studied and developed other "knobs to turn". These alternative technological concepts were themselves subject to progress, which explains how the rate of progress on the technologies could be tuned.

We find the same pattern in other ITWGs, which follow similar unlocking rules: identification of a need for a technological breakthrough, clarification of the technological concepts to be further explored and monitoring of the niches with relative positioning of the technologies.

Structuring a set of alternatives

To understand how a set of technological alternatives can be managed, we analyze the evolution of one such set over time. Figure 2 represents the structure of the potential solutions explored for lithography and the technological alternatives given in ITRS updates from 2001 to 2009.

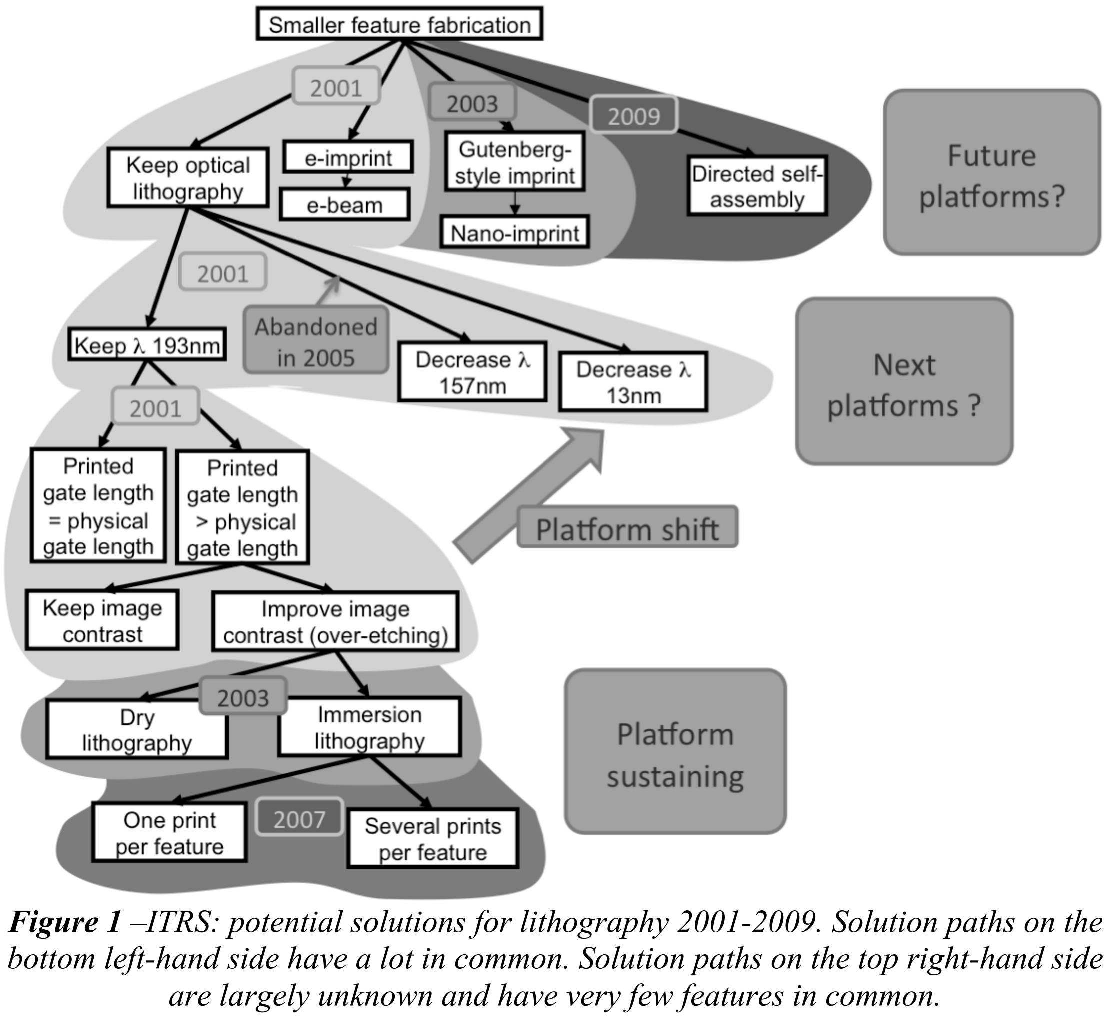

Figure 1 *–ITRS: potential solutions for lithography 2001-2009. Solution paths on the bottom left-hand side have a lot in common. Solution paths on the top right-hand side are largely unknown and have very few features in common.*

Since the engine of the semiconductor industry's evolution has been its ability to fabricate ever-tinier devices, one of its most recurrent research challenges has been to find ways to etch ever-smaller features. This part of the integrated circuit fabrication process is known as "lithography", and a whole research community is busy with its improvements. Within the ITRS, a specific ITWG is dedicated to its study. The finest resolution that can be reached by drawing with a laser is proportional to the wavelength of the illuminating light (Rayleigh principle). Since 1980, lithography equipment makers have therefore used lasers with decreasing wavelengths, ie 436nm, 365nm, 248nm and 193nm. Accordingly, the ITRS 2001 edition envisaged that optical lithography could be extended by developing 157 nm technology. Beyond 157 nm, solutions using extreme ultraviolet (EUV – 13nm wavelength) or electron-beam direct-write were to be developed. However, using a different illumination wavelength is a costly alternative. To prolong the lifetime of the 193nm platform, several alternatives were indicated, such as controlled over-etching, and the development of better resists, to improve image contrast. These alternative technologies concerned breakthrough paths, e.g. distinguishing between printed gate length (following Rayleigh) and the final "physical" gate, hence allowing to decrease the latter while keeping the same wavelength.

Over time, the different niches built an interesting pattern. At a low level, new technology candidates were continuously introduced to reach the functional requirements *within* the existing platform. They shared many attributes with the existing platform. *Many of these new technology candidates nonetheless broke away from some parts of the existing paradigms* (eg "physical gate length = printed gate length" and "one print per feature" were respectively broken by over-etching and double patterning).

In parallel, research continued on the next platform: 157nm (until 2005) and Extreme UV, which requires the creation of in-depth knowledge on refraction optics.

On a third level, significant research efforts were also being made on another disruptive challenger, multiple e-beam lithography. Finally, "out-of-the-box" technologies were given visibility, by being included in the list of potential solutions, even though they were very abstract technological concepts (see "directed self-assembly" or nano-imprints).

ITWG niche management therefore appears to be based on unlocking rules. They do not offer alternative, emerging technologies, but monitor their emergence and differentiation. Using a biological metaphor, unlocking rules do not emerge in a selection process but in a speciation process: several distinct cells, presenting complementary features, can finally emerge from "stem" cells.

Unlocking rules for collective work at the meso-level.

Building potential solutions: handling divergent positions and negotiating in the unknown

How do the actors work together to build a set of alternatives? What are the rules for collective work? We describe how new candidates for potential solutions were discussed in a specific field, device architecture. In late 2009 / early 2010, at the request of major memory manufacturers, two working groups held seminars to "reach approximate consensus on any "New Memory" technologies sufficiently mature to benefit from accelerated development" (internal working document). For each technology, proponents presented the pros and cons and the research needed, and circulated a white paper prior to the meeting. A "friendly critic" then presented a balanced assessment and finally, votes and discussions helped to identify critical research needs.

A closer look at the process reveals that far from being a judging process, it was a knowledge-building and knowledge-sharing one. For instance, the voting criteria were not decided on before the process began, but after the review of the white papers, ie taking into account the knowledge on the topic acquired during the process itself. Likewise, over the course of the face-to-face meeting, the classification of the technologies under review was changed, from 4 to 5 families, with some technologies moving from one family to another.

The ITWGs explained in a caveat that "the intent of this recommendation is to highlight technologies for additional roadmapping investment – but not at the expense of investment in or exploration of other candidates' approaches. We are not picking winners and losers". This was indeed the case, since *all the technologies studied during the exercise were still present in the August draft versions of the 2011 ITRS edition*.

Conditions for sharing information: collaboration and competition

Why do members take an active part in collaborative processes of this sort? Our data shows that disruptive technologies for semiconductors require transformations in large areas of the ecosystem. Alone, the disruptive innovator has very little chance of meeting all the conditions of compatibility in a complex, evolving system. We analyzed the schedules of ITRS meetings in detail. A working group typically spends between half and two thirds of the duration of the meeting in interaction with other working groups. The experts of one ITWG discuss, in detail, how the technological alternatives addressed by their own ITWG interact with those of the other ITWGs. The ITRS provides an arena to support the early propagation and integration of disruptive technologies: the innovators can benefit from early criticism; the providers of complementary technologies and the integrator can prepare for early integration; even the providers of incumbent technology can set relevant targets for their own technology developments.

Why do members participate *fairly*? According to ITRS participants, the different ITRS processes, such as regular updates, cross-ITWG meetings, regular evaluations, etc., all make it difficult for one actor to appropriate the proceedings for its own purposes. A free-rider is always possible, but would be rapidly excluded.

Conclusions

A model of regime in transition, based on strong unlocking rules

The ITRS illustrates a model of a regime in transition that does not follow the archetypal "evolutionary" pattern but is more based on a synergistic interplay between niches and the regime level. With regard to models of regimes in transition, we draw the following conclusions.

First, transitions rely heavily on unlocking rules.

- Regulative rules: the official goals of ITRS consist in opening new paths "yet to be blazed" and in identifying the limit of the technical norms stabilized in the past generation in order to put them into movement.
- Normative rules: at ITRS, the "proper" behaviour does not consist in "hiding" disruptive questions. On the contrary, the organizational routines all aim at *revealing the open issues* and the expected breakthrough, with the identification of technical challenges, rigorous monitoring of alternative technologies and regular comparisons between alternatives, putting potential technologies to the test of all the facets of the systems. The ITRS system is

based on co-stimulation, friendly criticism and support for technology development. "Don't pick winners or losers" is the norm used to stimulate proposals, encourage participants, support the initiatives and to enrich and extend paths.

- Cognitive unlocking rules are particularly striking at ITRS. The first is Moore's law. As described above, Moore's law does not lock-in but unlocks, in the sense that it stimulates radical technological innovation as well as disruptive market explorations. In dealing with niches, ITRS' basic cognitive rules consist in identifying and generating alternative technologies to make sure that the future performances will be met. It systematically builds multiple alternatives to each existing technology, encompassing improvements to the technological platform, emergence and preparation of credible alternatives (the next platform) and the proposal of crazy ideas. The logic of ITRS consists in regularly *increasing* the variety of alternatives (instead of selecting).

The logic of a system with unlocking rules: an ecology of concepts of socio-technical systems

Second, we confirm that in a situation with many unlocking rules, the actors work on the incumbent system as well as the alternative niches. The case study provides conceptual refinements on this extended "system".

ITRS actors use knowledge on the existing socio-technical system (its limits, design parameters, value, predictable improvements, etc.) but also work on several future alternative technologies addressed, or to be addressed, in niches. In these descriptions, emerging technologies are still partially unknown. In a regime in transition, the borders of the "system" have to be extended to the bundle of alternatives around this system.

This bundle of technologies has a series of structures and interdependencies. Some alternatives have a lot in common. They are all part of the same platform or paradigm (the lithography paradigm using the 193nm laser). Others, on the contrary, break some rules at a very high level (e-beam, Gutenberg-style imprints, self-assembly, etc. all break the design rule "with lithography") or a lower level ("a lithography device based on Extreme UV (13nm) laser"). Over time, ITRS tends to *maintain a structured set of technological alternatives*, with three main types of expansions: improvements to the existing platform, creation and maturation of reasonable medium-term alternatives and crazy explorations.

There is a critical dynamic underlying this structured set. The dynamics are not only defined by the competition and selection processes but also by variety generation, synergies and speciation:

- Variety (re)generation: some niches help generate new ones, with a view to constantly maintaining the capacity to reach the required performance over time.
- Symbiosis: in ITRS, niches combine into more sophisticated solutions, as learning in one niche supports expansion in another.
- Speciation: niches evolve in accordance with evolution in other niches, not by competing with each other but in order to reach a mutually beneficial positioning to cover specific performance areas.

Finally, unlocking rules generate and are based on what can be called an *ecology of concepts of socio-technical systems*. The notion of ecology of concepts helps to characterize the structure of the alternatives that the actors are able to imagine and work on at a certain point in time. It underlines that the alternatives in this ecology grow together, with synergies and interdependent speciation.

The logic of actors working with unlocking rules: college of the unknown.

Third, we confirm that in a situation with unlocking rules, actors work in close collaboration. In the evolutionary model of transitions, only a few, "deviant" actors work in niches on alternative technology; the semiconductor industry follows a model of collaboration in the unknown. We can refine our description of this collaboration.

The collaborating actors are both "technology suppliers" and technology "users" (Intel, STMicroelectronics, Infineon, etc.), who are themselves strong designers. In this regime in transition(s), all the actors are able to set innovative targets, to investigate technology breakthroughs, to explore the new uses of emerging technologies, etc.

These actors do not necessarily share competences (which would be critical for confidentiality and IPR reasons), they discuss the *nature* of the open questions, unsolved problems and critical challenges. In this "exchange in the unknown", the "supplier" provides "ideas" and "stimuli" to support the design activities of the "receiver". The unlocking rules described above correspond to the rules governing the interactions between designers at this meso-level: they do not select each other ("we don't pick winners or losers"); beyond mutual prescription, the actors in ITRS interact as "design stimulators". They *inspire* each other. This logic of inspiration between actors is well known in art (artists in artistic milieus inspire each other and the artists inspire the viewers). Whereas usual approaches in technology management tend to underline evaluation-selection logics or prescription logics, ITRS provides *inspiration-based coordination between designing actors*.

ITRS gives visibility to a network of interactions that are mainly oriented towards enriching the ecology of concepts. We label this organization a *college of the unknown*, by analogy with the "invisible colleges" of Diana Crane (Crane 1972) who, studying research networks, noticed that a clique of researchers with direct and indirect links were influencing the works of the rest of the community. ITRS is also a college, where members know each other and have a great influence on the rest of the industry. However, this college is not oriented toward one scientific field but to the exploration of emerging technologies and the sustained renewal of the ecology of concepts.

ITRS illustrates a model of regimes in transition. It does not follow the "evolutionary" pattern but a generative, interactive model. It is based on unlocking rules (instead of locking rules), which support collegial work in the unknown (instead of independent, competing entrepreneurs) and maintain an ecology of concepts of socio-technical systems (instead of an evolutionary pathway of niches) (see figure 3 below).

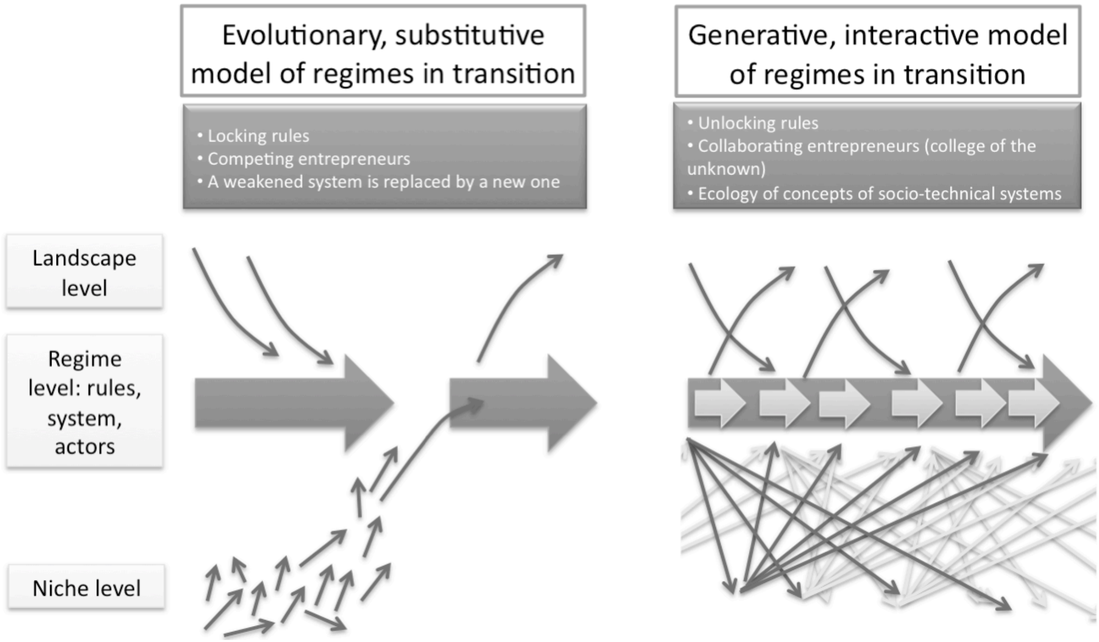

Figure 2 *– Regimes in transition with unlocking rules vs. locking rules*

More generally speaking, this model, inspired by transition management and technological innovation systems, calls for further research on alternatives to the evolutionary model. It represents a form of sustained breakthrough innovation, organized at meso-level and involving intensive design activities. It suggests a design regime, ie a regime whose logic is the constant "transition" or, better still, the constant renewal of products, competences and uses. Such a design regime can be characterized by the design capacities of the actors, by the design rules that link these actors and by the ecology of concepts structuring their efforts. When design capacities are limited, when design rules focus on conformation, when the ecology of concepts is fixed by the representation of the existing socio-technical system, then the design regime is stabilized into one socio-technical regime and plagued by waiting games. When design capacities increase and become more collective, inside colleges dealing with the unknown, when unlocking rules are introduced, when the ecology of concepts is living and constantly enriched, then more dynamic design regimes emerge. Today, the semiconductor industry is a good example of such a design regime. Doubtless other industries are also currently undergoing transformation, from a stabilized to a more dynamic design regime. The notions of unlocking rules, ecology of concepts and college of the unknown might help guide their transformation and provide new insights for public policies to support it.

Biographies

Armand Hatchuel, Pascal Le Masson and Benoit Weil are Professors at MINES ParisTech, for the Design Theory and Methods for Innovation chair. Their last book, Strategic Management of Innovation and Design, was published by Cambridge University Press in 2010. Armand Hatchuel and Benoit Weil are deputy directors of the Center for Management Science at MINES ParisTech. Armand Hatchuel is a member of the French Academy of Technologies and columnist for management issues at Le Monde.

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