Technological regimes: taking stock, looking ahead

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Abstract: This concluding contribution to the special issue on technological regimes discusses specific strengths and weaknesses of the regime concept and their implications for further conceptual and theoretical work as well as for empirical studies employing the regime concept. Four issues are addressed: the idea that technological regimes are rule-sets, the explanatory power of technological regimes, the empirical and conceptual boundaries of technological regimes and the dynamics of technological regime shifts or transformations.

Keywords: Technological regimes; rules; social explanation; boundaries of a regime; technological change; regime transformations; governance.

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1 Introduction

The concept of technological regime has emerged as an appealing concept for studying technological stability and change. Technologies do not change haphazardly, and so there is a need for understanding why certain patterns arise in technical development, but also in how and why these patterns may change. As we explained in the introduction to this special issue, the 'regime' concept seems particularly appropriate for such explanatory purposes.

In this concluding contribution we will assess specific strengths and weaknesses of the regime concept. We do so on the basis of the other contributions made to this special issue and - where useful or necessary - with reference to more general conceptual and theoretical discussions in technology dynamics and social science. This editorial therefore does not try to add up some of the substantive empirical conclusions from the different contributions, although this would be an interesting effort in its own right. Rather, we focus on conceptual and methodological lessons that can be learned from the contributions to this special issue and that might guide further investigations - theoretical as well as empirical - using the regime concept.

Four issues will be addressed. We start with discussing the idea that technological regimes are rule-sets and discuss peculiar difficulties with seeing some elements - which figure in empirical analyses of technological regimes - as rules. The next issue we discuss is the explanatory power of the regime concept, focusing in particular on what the notion of 'rule' can do in explaining technological development. The third section discusses the boundaries - empirical as well as conceptual - of technological regimes. In a final section we consider some relevant issues with respect to the dynamics of technological change, both within the bounds of an existing regime as well as in the case of regime transformation.

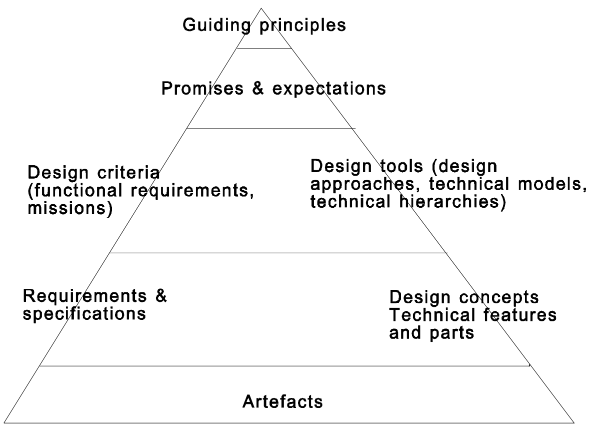
2 Regimes as rule-sets

Although there is no consensus in the literature on what exactly are the constituting behavioural elements of technological regimes, rules are usually seen as the central ingredient of technological regimes [1]. However, as Franssen argues in his contribution, a clear definition of the notion of 'rule' seems to be lacking. Franssen also comes to the conclusion that some of the constituting elements in what he calls the broad notion of technological regime cannot be plausibly seen as rules: "Some of its alleged components cannot plausibly be seen as behavioural elements at all, such as product characteristics and infrastructures. Other components are better seen as the complex interplay of many behavioural elements, such as institutions per se. … Some again may be analysed as regular but not as forming a rule-set, as was argued … for skills.” (Franssen, this issue)

The observations of Franssen raise a number of questions for the other contributions to this special issue. One is what (behavioural) elements the different authors see, or use in their analysis, as the constituting elements of a technological regime. The other question is whether these elements can plausibly be analysed as rules. It should be noted, in using the notion of ‘element’ here, that there are major differences with the notion of element of a physical system (cf. [2]). For most social systems, the ‘element-of’ relation is, for instance, not transitive. Therefore, although models may form part of the rules of a technological regime, they are not necessarily themselves elements of the regime. Below, we will address both questions and try to reach some general conclusions on what this implies for the further conceptualisation and use of the notion of technological regime.

Of the various contributions, Moors and Mulder remain the closest to the original definition of technological regime proposed by Nelson and Winter [3]. They analyse the technological regimes of tyre and zinc production merely in terms of the search heuristics of engineers and in terms of a basic concept or dominant design. The other authors use a somewhat broader notion of the concept of technological regime. Ravesteijn sees technological regimes “as basically consisting of design, construction and management rules for (complex) artefacts”. To give flesh and bone to these rules, he particularly uses the triangle of technological development as proposed by Van de Poel [4,5] (see Figure 1). Ertsen uses this triangle also as inspiration, although in his analysis of irrigation regimes he confines himself to guiding principles, design criteria and artefacts. Van de Poel, Hale and Goossens also use the triangle, but in addition see the roles of the various actors involved in the development and use of a technology as part of the technological regime. In their actual analysis, the emphasis is not primarily on the rules that are shown in Figure 1, but on rules that are relevant for safety and they emphasise the importance of informal in addition to, and sometimes in contrast with, the formal rules laid down by the regulator. Verheul, finally, relates the notion of ‘technological regime’ to the more general notion of ‘institution’. He mainly pays attention to roles and sees particular rules for interaction between the relevant actors as connected to, or following from, these roles.

Figure 1 Triangle of technological development [4,5]



Although the authors use somewhat different constituting elements of technological regimes in their empirical analyses, this does not rule out the possibility of one common underlying notion. In this notion, such elements as search heuristics, dominant designs, the rules outlined in Figure 1 and roles of actors are the elements that constitute a technological regime. On this interpretation, the differences between the contributions would not flow from different uses of the notion of technological regime but from pragmatic differences in explanatory aims. Different explanatory aims result in somewhat different elements of technological regimes being central in the empirical analysis.

Another question is whether the mentioned elements can plausibly be seen as constituting a 'rule-set' or 'grammar'. For some of the elements mentioned by the authors, it can convincingly be argued that they may be conceptualised as rules or rule-sets. An example is roles. Boudon defines a role as "the group of norms to which the holder of the role is supposed to subscribe" [6, p.40]. These norms, or rules, may be upheld by an overarching organisation, such as in the case of the roles of teacher and pupil, but this is not necessarily so. Like rules, roles coordinate the behaviour of actors vis-à-vis each other because they create mutual expectations and make the actions of other actors more predictable [7].

For other elements, it is more questionable whether they can be conceptualised as rules. An example is technical models. These are representations of a class of technical artefacts showing their (underlying) structure and function. Technical models "define functional dependencies between parts of the artifact and between critical parameters, dependencies between various performances of the artifact and dependencies between the parts, the parameters and performances" [8, p.19]. According to Disco, Rip and Van der Meulen [9]

> "[i]n the classic configuration of the 19th and early 20th centuries ... technical models generally started out as local and ad hoc constructions, and only later tended to become stabilized within the cosmopolitan culture as standard generators of design heuristics. The construction of technical models ... gradually became a distinct type of activity within the overall process of engineering design, i.e. ... gradually became the province of research specialists within a cosmopolitan division of technological labor" [9, p.477].

Commonly accepted technical models thus serve to coordinate activities between different locations, pre-eminently companies, where artefacts are designed, for example by suggesting heuristics and by functioning as means for evaluation of designs, as well as between design activities and research activities that aim at the optimisation of technical models. Technical models can thus be said to contribute to, and enable, collective coordination, just like rules do.

Now, can technical models be conceptualised as rules? Although there is no consensus on the definition of the concept of rule, it is clear that one characteristic of rules is that they make it possible to distinguish 'right' or 'allowable' actions from 'wrong' or 'unallowable' actions [10]. It is questionable whether technical models per se have this feature. Technical models are design tools that can be employed or not in a design process. Certainly, they suggest certain rules like search heuristics and rules for the evaluation of a design may refer to technical models. However, as long as there is no rule prescribing the use of a technical model in specific circumstances or for specific purposes, the existence of a technical model hardly distinguishes allowable actions from inadmissible ones [11,12]. So, it seems somewhat odd to call a technical model itself a rule.

Nevertheless, technical models - and other design tools like handbooks - are important for understanding the genesis and continued existence of technological regimes, as argued by, for example, Disco, Rip and Van der Meulen [9]. Technical models and the like are therefore important ingredients in rule-following action with respect to technology. This is the case because rules in technological development often refer to design tools like technical models. But that is not the same as saying that technical models are rules. Conceptually, it is perhaps more appropriate to say that technical regimes are rule-sets and that other behavioural elements and concepts, including the notion of technical model, may be required to understand the emergence and 'working' of technological regimes.

For those who (want to) employ the concept of technological regimes in empirical studies or for steering purpose, the main lesson of the above is that one should be aware of the conceptual boundaries of the concept of regime and that of rule. We will further elaborate on this issue in the section on the boundaries of technological regimes.

3 What explanatory power does the concept of a technological regime have?

The concept of a technological regime was explicitly coined to serve in accounts that explain technological development, either in the form of changes in technology or in the form of the absence of changes. The latter is, given that technology is a social phenomenon, perhaps even more in need of explanation than the former. An important question is what the explanatory power of the concept is and how it can perform its explanatory role. The mere introduction of a concept is not sufficient to claim explanatory power. It will, for instance, not do to say that a particular form of technical innovation was not developed 'because it did not fit into the existing technological regime'. The explication of a concept nevertheless serves as a kind of embryonic theory. If a technological regime is conceived as a set of rules, then to say that a technique was not developed because it did not fit into the existing technological regime is to say that certain rules existed that prevented or obstructed the development of the technique. This is no longer an empty statement. At the same time, in order to have explanatory value such a statement will have to be substantiated. It will have to be made clear how such things as rules help to explain social, and more specifically technological, development.

Clarity about the explanatory potential of the concept of a technological regime, as well as of any alternative concept, is not just relevant to the satisfaction of our desire to understand our world. Philosophically explanation and prediction are closely linked. An adequate explanation of a phenomenon post factum should have enabled a prediction of the same phenomenon if available ante factum. Although for the social sciences this can only be an ideal, the ability to explain observed phenomena must certainly serve as an indication of the ability to anticipate the effects of specific policies that aim to steer the development of technology in desired directions.

Philosophical accounts of explanation just referred to generally see either a reference to regularities and (descriptive) laws or a reference to causal mechanisms as a necessary condition [13]. For the social sciences a reference to regularities and laws is notoriously problematic. At the level of the social phenomena themselves, few, if any, regularities have been discovered that have direct explanatory force. An account that makes causal mechanisms the central ingredient of social explanations seems therefore more promising [14]. The prime candidate for a causal force in social phenomena seems to be human agency. Human action directly brings about changes in the environment, but also indirectly, through affecting the beliefs, attitudes and actions of other people, whereas for most other entities in terms of which social phenomena are conceived, such as groups, institutions, structures, etc., it is much more difficult to clarify what their place in the causal order of things is.

It is felt, however, that a major difficulty for this causal approach is to link adequately the individual level, where the causal forces are working, to the societal level, at which the interesting phenomena of development and change that are to be explained are generally identified. This is often called the micro-to-macro problem. On the one hand, these social phenomena somehow result from the actions of the people participating in them, but not always through the same simple mechanism, as these actions can be expressly aimed at creating the social phenomenon but more often are not, such that the resulting phenomenon was not intended by anyone in particular. On the other hand, people do not act in a vacuum. The social arrangements that are seen as resulting from the actions of many individuals at the same time are a continuous presence in shaping the beliefs, expectations, attitudes, preferences and ultimately actions of these individuals. People are constrained by social conditions in their actions. Social phenomena are therefore both explananda and conditions in the explanantia.

The notion of a rule or rule set holds the prospect of a link between the micro and macro levels. All rules have in common that they guide individual action. At the same they are generally social in character in being shared among various individuals and in serving to coordinate the actions of several people [15]. This is taken up by social sciences in more than one way, however. For some, rules and rule sets are explicitly distinguished to serve as an intermediary level in the explanation of social phenomena [16]. For others, however, in a tradition that has strong roots in economics, rules are, in their status of social 'molecules', the first candidates to be explained [17]. In the present contributions, the notion of a technological regime [18] is used as an intermediary concept. Its primary function is, therefore, to establish an explanatory relation between individual actors and the social phenomena they both produce and live by. The emergence of action-guiding rules as entities in the social world is then left unexplained, which is not problematic as long as it is realised that this could be subject to further explanation.

Nevertheless, not all social structure can be viewed as rule sets or institutional arrangements, and human action is guided by more rules than the ones that are sensibly incorporated into a technological regime, however broadly conceived. Explanations of specific forms of technological development will therefore probably have to take recourse to other concepts as well, and it is an important question what other concepts might be necessary.

The regime perspective itself can be seen as constraining the range of acceptable concepts. By conceiving regimes as sets of action-guiding rules, it sees social phenomena as ultimately originating in individual human actions. Other concepts that are brought in to explain phenomena should lend themselves to be naturally linked to individual action. Thus a mere reference to a particular dominant 'culture' would therefore hardly help in explaining anything as long as it is not clear how this ‘culture’ translates to, say, values that are ‘alive’ to the minds of the people whose actions are considered.

Among the concepts referred to in the contributions to this volume, a distinction can be made between behavioural and non-behavioural factors. Among the latter can be counted the physical constraints of what there is: infrastructure, implemented production techniques, etc. These often considerably narrow the directions in which solutions to existing or emerging problems can be sought. Their importance is especially emphasised in the contribution by Moors and Mulder but they can also be seen at work in the contributions of Ertsen and Ravesteijn.

Among the behavioural concepts, those referring to the political context seem to play a larger role in the contributions than those referring to the economic context. This is, for instance, the case in the contributions by Van de Poel, Hale and Goossens and by Ravesteijn. It cannot be said, however, that the present contributions suggest ways to conceptualise these contexts, or the interaction between them, and the technological regime. They are treated mostly as exogenous, making their presence felt in the form of decisions, requirements, incentives and the like, from ‘outside’ as it were. Nonetheless, given the origin of the concept of a technological regime in the economics literature, the contributions to this issue can also been seen as attempts to explore the explanatory value of the concept outside of economic phenomena.

4 The boundaries of a regime

The compelling nature of technological regimes was stressed in all of the contributions in this special issue. Rules comprising an existing technological regime exert an influence on its future development. Following the critical analysis of the central concept of rules that preceded, it now needs to be asked exactly *which* rules exert the influence? What are the boundaries of a regime?

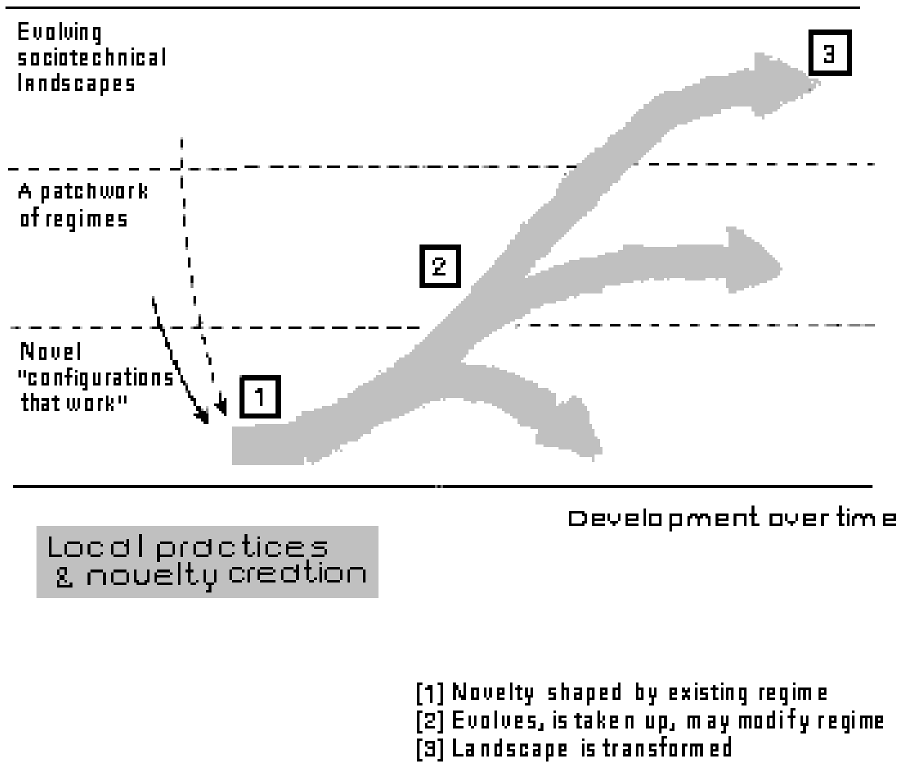
Regimes can be understood to have several kinds of boundaries. Certainly, empirically, a particular technological regime will have boundaries. Without boundaries, studying a phenomenon would be an insurmountable task. Philosophically, however, one may observe that a concept without boundaries will not be able to help explain anything. In the growing number of studies that use the concept of technological regime, boundaries of each regime are explicitly or implicitly recognised in different ways.

Van de Poel, Hale and Goossens explicitly delineate the boundaries of the technological regime related to safety and environmental issues *geographically*. The North Sea and its surrounding countries that exploit it in search of oil and gas constitute one single regime. Technological developments are not (much) influenced by developments beyond these geographical boundaries. Ertsen and Ravesteijn are even more specific and relate to Java.

The fact that *historical* boundaries of the particular regimes are widely acknowledged is perhaps not surprising. Indeed, the very concept of the technological regime seems to invite historical investigation (see Ravesteijn, this issue). Regularities in the development of technology, and interrelations between technological artefacts have been the starting point for developing a concept such as that of a technological regime. Nevertheless, empirically, the technological regimes analysed are shown to grow from previous regimes, where the dividing line between the one regime and the next is difficult to draw. One could perceive of technological development as a *cascade* of regimes; the influence of one regime on the next is not always clearly visible (see also [19]), especially as sub-regimes are also recognised within this approach. The dividing line is difficult to draw, and it remains a judgement-call depending much on the perspective that the academic researcher takes.

Given the ambiguities surrounding the notion of technological regime, noted as well in the previous sections of this concluding article, one would be wise to be explicit about the boundaries for the regime studied, even if one would acknowledge that the exact place where the boundaries are drawn is open for discussion.

Figure 2 The relation between the micro, meso and macro level in the dynamics of socio-technical change as conceptualised in Kemp, Rip and Schot [20, Figure 10.1]



Whilst the question about the empirical boundaries of a technological regime are relatively straightforward, this does not hold for the conceptual boundaries. Conceptually, in the views developed by Rip and Kemp [1], Kemp, Schot and Hoogma [21], Kemp, Rip and Schot [20] a technological regime is a concept at the meso level of analysis. It is thus separated from the macro level of the social or sociotechnical landscape (see Figure 2) [22]. At the micro level of the individual agents (human beings, organisations), novel configurations are thought to emerge. When such novel configurations are 'strategically' 'managed', they can find a 'niche market' where users 'experiment' with the 'technology' [23]. The need for broad and deep learning by users, for instance, is emphasised. However, how exactly agents learn and interact with each other so that novel configurations might indeed alter existing regimes is as yet unexplored. The conceptual link between the micro and the meso level might need additional, complementary insights (as argued by Ravesteijn in this issue, as well as in the preceding section of this contribution), such as those from actor-network theory. "Judiciously applying economic (or social, for that matter) incentives and disincentives" is alluded to [20], but a more elaborate, less ad hoc (cf. Verheul in this issue), theory that would explain human behaviour and fit the framework seems to be needed.

Similarly, the relation between a technological regime and a sociotechnical system at the macro level is unclear. A sociotechnical landscape, defined as a "landscape we live in … composed of networks of infrastructures combined with nodes like the office or the city" is where a regime is supposed to be 'nested in' [24]. But what the relation between the landscape and the regime is, exactly, is yet to be specified. Indeed, when suggesting a difference between a regime and a landscape, where the latter is a broader category wherein the former is nested, one is led to believe that, conceptually, within the theoretical framework developing the notion of technological regime, boundaries of that concept must be acknowledged. In response to this question, Rip has responded, however, that a "regime as grammar or rule-set has no (social) environment" [25].

To indicate that such a statement is untenable, it is useful to explicate the analogy with language. Part of the inspiration for the concept of a technological regime as a grammar seems to lie in (one point of view developed in) the philosophy of language (see, most notably, [12]) [26]. In this field of research it is, however, despite the authority of Wittgenstein, a not uncontested issue to present language as having no environment, as being all-encompassing, even among philosophers of language (see [27]). The question about the possibility of understanding language and the 'real world out there' without using language might, however, be of a different nature than the question about the possibility of understanding technology and technological development without the concept of a technological regime as a grammar of rule-set.

Conceptual boundaries internal to the theoretical framework where the 'technological regime' is developed as a tool for analysis are one issue. Another is the distinctions between the concept of a technological regime and other concepts in related literatures. Here, we do not want so much to draw attention to the similarities between the concept of technological regime, on the one hand, and those of 'technological paradigm' [28], 'techno-economic paradigm' [29], 'technological system' [30], or still others on the other hand. These have already been alluded to in the introduction to this special issue. Instead, we want to point to some constituent parts of the concept of technological regime, and how these are linked to and may easily be confused with other concepts. It seems that, as an empirical study enters into more detail, it is not unlikely that what prima facie seemed to be made understandable by the concept of technological regime may actually be described as well or better in terms of other, related concepts. In an attempt to escape the broad nature of the concept of technological regime, and focus on single (set of) rules and/or artefacts, thus escaping the problem of being too unconscious about the empirical boundaries of a regime, one could paradoxically reach the bounds of the concept of the technological regime. Especially when focusing on artefacts that have ceased to develop in a technical sense in a major way, and where market dynamics are of relatively greater importance, this seems to be the case. The concept that immediately comes to mind here is that of a *standard*. The concept of standard emanates from the management and economics literature [31]. Although this is rare, the literature on standards could complement an analysis in terms of technological regime, thus benefiting research (cf. Moors and Mulder in this issue).

5 The dynamics of technological change and regime transformation

If a theory of technical development is to be relevant for steering or managing technology, it has to provide insight into both technological stability and change. Whilst the concept of technological regime was introduced to account for the cumulative and patterned character of technological development, studies on technological regimes do also provide insight into technological change and shifts in, or transformation of, technological regimes.

One of the things that has become clear from studies on technological regimes is that new regimes usually grow out of old ones (see [19]). This insight is nicely illustrated in the contribution of Ravesteijn. He shows in some detail how the technical-agricultural irrigation regime grew out of the technical irrigation regime. As he states: "a technological regime shift is not something that all of sudden comes out the blue, but rather a gradual transformation, though its actual consequences - the artefacts to which it leads - might suddenly come up". The latter consequence is related to the fact that plans for irrigation projects in the Dutch East Indies had a lead time of some decades. Also in the contribution of Mulder and Moors, (potential) new regimes in tyre and zinc production grew out of old ones; many of the rules of the new regimes are similar to the old ones. Van de Poel, Hale and Goossens stress the historical and interrelated character of regime rules. This not only means that the origination of new rules is conditioned by existing rules but also that the degree to which existing rules (can) change depends on the degree to which other rules change. In their case, this meant that what was occurring was not a complete transformation of the existing regime, but rather a change in some of the rules.

It is important to realise that technological change does not necessarily require a regime shift or transformation; technological change may also occur within the bounds of an existing regime. Ertsen describes the "quest for the perfect structure" in the Dutch East Indies as taking place in a context where criteria and guiding principles have been settled, i.e. within the context of an established technological regime. An example of technological change within the bounds of a technological regime is also the promise-requirement cycle [32]. Promises or expectations that are shared within a technological regime will be translated into requirements that guide the innovative activities of the actors involved. The idea that technological regimes have a dynamic element was in fact already part of Nelson and Winter's conception of technological regimes. As they stress,

> "[t]he sense of potential, of constraints, and of not yet exploited opportunities, implicit in a regime focuses the attention of engineers on certain directions in which progress is possible, and provides strong guidance as to the tactics likely to be fruitful for probing in that direction. In other words, a regime not only defines boundaries, but also trajectories to those boundaries" [3, p.57].

So, it seems possible to make a distinction between technological change within the bounds of a technological regime and a change in the regime itself, a phenomenon usually described as regime shift or regime transformation. This raises the conceptual question in which cases we can speak of a regime transformation. One way to tackle this issue would be to make a distinction between core rules that are constitutive for a technological regime and peripheral rules that guide technical development and interactions between actors but are not constitutive for the regime (cf. [19]) [33]. Core rules in such an approach would be related to guiding principles, promises and expectations and design criteria. Whilst this may be a useful way to define regime transformations or shifts, it is clear that the difference with dynamics within the bounds of an existing regime is fluid.

Whether technological change takes place within the bounds of the existing regime or not, insight in that regime is required to understand it and to develop options for steering and governance. Taking account of the current regime may be a useful way to prevent certain unpleasant surprises in employing policy instruments. The idea of stretch and fit, proposed by Verheul, may be a good strategy for devising governance options that take account of current technological regimes. On the basis of this, Verheul proposes specific strategies like coercion, external pressure and the utilisation of mimetics. More important perhaps than these specific strategies is the general idea that the design of governance options should be based on an analysis of the current regime and on existing possibilities for change.

Both the understanding of technological change and the design of governance options require insight into the dynamics of regime shifts or transformations. The concept of technological regime itself cannot completely explain the transformation from one regime to the other. Therefore other concepts are also required, and the vast literature on technological change may offer some help here. In Section 3 the general issue of which other concepts the various contributions to this issue bring into their explanations using the notion of technological regime was briefly discussed. Concerning regime shifts, some ideas are developed in the contribution of Mulder and Moors. They suggest two important mechanisms for regime transformation: competition and proactive innovation.

The importance of competition is especially visible in the tyres case. Competition between bias ply and radial tires, products of two distinct technological regimes, led to the introduction of the bias belted tyre in the regime of bias tyres. So competition between products of different technological regimes may lead to significant changes in both regimes. This is an important addition to the general insight that competition furthers innovation within the bounds of an existing regime [34].

Proactive innovation is the phenomenon that companies develop innovations in anticipation of new user needs or new regulations. Mulder and Moors describe a number of proactive innovations in the zinc production regime. Although not all of these innovations have yet been successful, their availability enables future technological change and a transformation of the current regime. Proactive development of innovations is a more general phenomenon and it can be shown that in some technical or industrial sectors it is more likely to take place than in others [4].

In the literature on technological regimes, other mechanisms for regime shifts have been distinguished as well. These include the role of niches and the role of outsiders [1,5,20,21]. We will not review these insights here.

6 Conclusions

We introduced the concept of ‘technological regime’ as a promising concept for understanding and explaining technological stability and change in the introduction to the special issue. We can now conclude - on the basis of the contributions and this editorial - that the concept indeed has a descriptive, explanatory and predictive power that can also be put to work in concrete cases. The concept of ‘technological regime’ can not only be used to describe the cumulative and patterned character of technological development, but is also important in explaining it. Moreover, the concept can be used in the design of governance options with respect to technology.

Despite the usefulness of the regime concept, it has also become clear that certain problems are connected with the concept and its use. One is that the notion of rule, which is central to the concept of technological regime, is conceptually less than clear. One consequence is that different authors sometimes seem to speak about regimes while they mean different things. This does, of course, not make the regime concept useless but it means that one should be very careful in making clear what one means when one speaks about a technological regime or about an ‘element’ of a technological regime. Empirical analyses, in other words, should be reflexive about the conceptual difficulties in employing the concept of ‘technological regime’. We hope that this special issue contributes to this reflexivity.

Another conclusion is that the concept of ‘technological regime’ *alone* is not enough to understand and explain technological stability and change. Other concepts are required as well. This is hardly amazing given the diversity of empirical phenomena that is relevant for technological development. The observation that other concepts are required as well therefore cannot be called a weakness of the regime concept. However, as shown in Franssen’s contribution, there is a tendency to broaden the regime concept to include other relevant phenomena and concepts as well and to make the concept all encompassing. We believe that this is an undesirable strategy because it blurs the distinctions between empirically distinct phenomena and makes the concept conceptually opaque. Moreover, a concept with no boundaries eventually explains nothing.

Whilst the concept of ‘technological regime’ should not be made too broad, it should not be made too narrow either. In its most limited sense, the concept of ‘technological regime’ boils down to stating that a dominant design or technological trajectory exists. In that sense, the concept hardly adds anything to other existing concepts and does not help to understand or explain technological stability and change. As argued, it is the notion of ‘rule’ - however problematic this notion still may be conceptually - that gives the concept of ‘technological regime’ an added value. Although we have not systematically compared the regime concept to other available concepts, it seems safe to conclude that the regime concept is unique in stressing the notion of rule, and in explaining technological stability and change in this way. For such reasons, the concept of technological regime is indispensable in any theory of technical development.

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6 Boudon, R. (1981) *The Logic of Social Action. An Introduction to Sociological Analysis*, Routledge and Kegan Paul, London.

7 This does not imply that roles simply prescribe the behaviour of actors. Roles define "an area of obligations and constraints that corresponds to an area of conditional autonomy" (Boudon, R. and Bourricaud, F. (1989) *A Critical Dictionary of Sociology*, Routledge, London, p.308).

8 Meulen, B. van de (1998) 'Coordination of ship propeller design: technical models and the relation of T.Y. Draco with Queen Elizabeth II', in C. Disco and B. van de Meulen (Eds.) *Getting New Technologies Together, Studies in Making Sociotechnical Order*, Walter de Gruyter, Berlin, pp.15–38.

9 Disco, C., Rip, A. and Meulen, B. van de (1992) 'Technical innovation and the universities. Divisions of labour in cosmopolitan technical regimes', *Social Science Information*, Vol. 31, pp.465–507.

10 This is not to say that making this distinction is always straightforward or uncontested.

11 It might be objected that rules also do not prescribe their own application (cf.[12] § 185-202, pp.74-81). However, Wittgenstein's point seems to be that rules themselves do not determine how they should be applied (if they are considered in isolation from the social practice in which they are applied). Here, the point is that technical models do not even determine that they should be applied, which is a different question from whether they determine how they should be applied if they are to be applied at all.

12 Wittgenstein, L. (1953) *Philosophische Untersuchungen*, Suhrkamp, Frankfurt am Main.

13 Key references are Hempel, C.G. (1965) *Aspects of Scientific Explanation*, New York, The Free Press, and Salmon, W.C. (1984) *Scientific Explanation and the Causal Structure of the World*, Princeton, Princeton University Press, respectively.

14 Authors who support this general methodological position in a context relevant to the present subject are Elster, J. (1983) *Explaining Technical Change. A Case Study in the Philosophy of Science*, Cambridge, etc.: Cambridge University Press and Parijs, Ph. van (1981) *Evolutionary Explanation in the Social Sciences. An Emerging Paradigm*, Totowa, N.J., Rowman and Littlefield, although they differ in the models of explanation they support.

15 Often the term institution is used for social entities that are 'made up' of rules guiding or prescribing individual action. As for other concepts, a generally agreed upon definition of institution is not available (Mäki, U., Gustafsson, B. and Knudsen, Ch. (Eds.) (1993) *Rationality, Institutions and Economic Methodology*, London/New York, Routledge, p.13 or Hechter, M., Opp, K.-D. and Wippler, R. (Eds.) (1990) *Social Institutions, Their Emergence, Maintenance, and Effects*, New York, Aldine de Gruyter, pp.13–14).

16 For instance Bohman, J. (1991) *New Philosophy of Social Science, Problems of Indeterminacy, Cambridge*, Polity Press and Hodgson, G. (1988) *Economics and Institutions, A Manifesto for a Modern Institutional Economics*, Cambridge, Polity Press.

17 Examples are Ullmann-Margalit, E. (1977) *The Emergence of Norms*, Oxford, Clarendon Press; Schotter, A. (1981) *The Economic Theory of Social Institutions*, Cambridge, etc., Cambridge University Press and Eggertsson, Th. (1990) *Economic Behaviour and Institutions*, Cambridge, etc., Cambridge University Press.

18 It is not very clear how the relation between the concepts of institution and regime should be seen. It seems that those authors who use the notion of a regime would use the term institution for social entities that show considerably more structure than consisting merely of sets of rules.

19 Ende, J. van den and Kemp, R. (1999) 'Technological transformation in history: how the computer regime grew out of existing computing regimes', *Research Policy*, Vol. 28, pp.833–51.

20 Kemp, R., Rip, A. and Schot, J. (2001) 'Constructing transition paths trough the management of niches', in, R. Garud and P. Karnøe (Eds.) *Path Dependence and Creation*, Lawrence Erlbaum, Mahwah (NJ) and London, pp.269–299.

21 Kemp, R., Schot, J. and Hoogma, R. (1998) 'Regime shifts to sustainability through processes of niche formation: the approach of strategic niche management', *Technology Analysis and Strategic Management*, Vol. 10, pp.175–195.

22 According to Kemp, Rip and Schot [20] the figure "shows that local practices, including those that involve novelty creation, occur in a context of regimes and the sociotechnical landscape, which exert influence on the shape and success of novel products".

23 Schot, J. and Rip, A. (1997) 'The past and future of constructive technology assessment', *Technological Forecasting and Social Change*, Vol. 54, pp.251–268.

24 Rip, A. (1995) 'Introduction of new technology: making use of recent insights from sociology and economics of technology', *Technology Analysis and Strategic Management*, Vol. 7, pp.417–431.

25 Private correspondence with one of the authors (Dolfsma), March 22, 1999, available on request.

26 In his Tractatus, Wittgenstein is clear on this point (Wittgenstein, L. (1963 [1921]) *Tractatus Logico-philosophicus*, Routledge and Kegan Paul, London). His other major work, it is necessary to observe, *Philosophical Investigations* [12], gives rise to a discussion as to whether Wittgenstein claims there that language is all-encompassing as well.

27 Searle, J.R. (1994) *The Social Construction of Reality*, Free Press, New York.

28 Dosi, G. (1982) 'Technological paradigms and technological trajectories: a suggested interpretation of the determinants and directions of technical change', *Research Policy*, Vol. 11, pp.147–162.

29 Freeman, C. and Perez, C. (1988) 'Structural crises of adjustment, business cycles and investment behaviour', in G. Dosi, C. Freeman, R. Nelson, G. Silverberg and L. Soete (Eds.) *Technical Change and Economic Theory*, Pinter, London, p.66.

30 Hughes, T.P. (1986) 'The seamless web: technology, science, etcetera, etcetera', *Social Studies of Science*, Vol. 16, pp.281–292.

31 See, for instance, Farrell, J. and Saloner, G. (1986) 'Installed base and compatibility: innovation, product preannouncement, and predation', *American Economic Review*, Vol. 76, pp.940–955 or Shapiro, C. and Varian, H.R. (1999) *Information Rules*, Harvard Business School Press, Boston, MA, especially chapter 9, including references.

32 Lente, H. van and Rip, A. (1998) 'Expectations in technological developments: an example of prospective structure to be filled in by agency', in, C. Disco and B. van de Meulen (Eds.) *Getting New Technologies Together. Studies in Making Sociotechnical Order*, Walter de Gruyter, Berlin, pp.203–230.

33 The idea of core and peripheral rules seems to have its antecedent in the philosophy of science, especially in Lakatos' idea that scientific research programs have a hard core and a protective belt around them (Lakatos, I. (1978) *The Methodology of Scientific Research Programmes*, Cambridge University Press, Cambridge, pp.47–52). The hard core is associated with negative heuristics - paths of research that are to be avoided; the protective belt with positive heuristics for the further development and testing of the research program.

34 In fact, whether competition furthers technical innovation depends on the issues on which companies compete. This may differ significantly between industrial sectors (see Pavitt, K. (1984) 'Sectoral patterns of technical change: towards a taxonomy and a theory' *Research Policy*, Vol. 13, pp.343–373).