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Pursuing the Alignment of Institutions to Technologies as a Policy Objective in Times of Technical Change

Daniel Scholten
PhD candidate
Delft University of Technology, Faculty of Technology, Policy and Management, section Economics of Infrastructures. Room B2.170, Jaffalaan 5, PO Box 5015,
2600 GA Delft, The Netherlands
Phone: 31-15-278-4708 – Fax: 31-15-278-7925 – Email: d.j.scholten@tudelft.nl

Abstract

This paper asks how governments can pursue the alignment of institutions to technologies in times of technical change as a policy objective. While the literature on the coevolution between institutions and technologies does a fine job in describing the general processes and highlighting the necessity of aligning institutions to technical changes, it fails in its explanation of which institutions would match what technologies and how governments could facilitate such an alignment. To overcome the first obstacle this paper explores the notion of coherence because it contains the means to compare and match institutions to technologies. To overcome the latter obstacle this paper digs deeper into theories on institutional evolution and coevolution in order to link 'coevolutionary situations' to the required policies for achieving alignment. Combined with the existing body of knowledge they may be able to create a framework for the pursuit of institutional alignment to technical changes. The aim is to explore the use of the two ideas in this regard. The paper finds that while the method of coherence is valuable in overcoming the first obstacle, it narrows the scope of the application of the overall framework to its definition of institutions and technologies. The model to derive policies for alignment seems promising but faces difficulties in application to situations further into the future and neglects what governments actually can do.

Keywords
Coevolution, institutions, technical change, coherence, alignment policy

1. Technological Change and Institutional Alignment

As many scholars have already noted, to be effective with new technologies, "a nation requires a set of institutions compatible with and supportive of them. The ones suitable for an earlier set of fundamental technologies may be quite inappropriate for the new" (Nelson 1994, 58 following Freeman and Perez). Indeed, history is full of examples where existing institutional structures pose an obstacle to the success of new technologies and complementary industries which "require institutional reform if they are to develop effectively" (Nelson 1994, 58). In his book 'Knowledge and Competitive Advantage' for example, Murmann shows how the coevolution between new technologies, industrial structures and scientific and governmental institutions allow the German dye industry to develop more rapidly than its British counterpart despite the latter's better starting position due to the fact that it lacked the coevolutionary synergy the German's enjoyed. Yet despite all efforts and achievements, the literature on the coevolution of institutions and technologies is still not able to instruct policy makers how to ensure that a transition to new technologies will be accompanied by the emergence of a set of institutions supportive of its functioning. Two primary reasons account for that. First, it is still unclear what "the characteristics of the institutions appropriate to a particular technology" are (Saviotti 2005, 25). Without a way to match certain institutions to specific (sets of) technologies, how is one to ensure alignment? Of course, these institutions must also be relevant for the development and diffusion of the technologies they govern. Second, the knowledge on how changes in technologies exactly affect institutions (and vice versa) is not sufficiently developed. As such, how governments can influence these processes also remains an open question. How should they formulate and execute a policy that aims at aligning institutions and technologies in a dynamic setting? What should governments do when and how to ensure coevolution?

This paper asks how governments can pursue the alignment of institutions to technologies in times of technical change as a policy objective. As such, it hopes to make progress on the two obstacles to the use of insights on the coevolution of institutions and technologies for policy purposes. It will do so by highlighting first the concept of coherence as developed by Künneke, Finger, Menard and Groenewegen in several articles over the last few years. 'Coherence' entails a way to analyze the effects of liberalization in network industries by assessing similarities and differences between the way the institutional and technological dimensions of networks are governed. Realizing its potential, the authors also experimented with the use of 'coherence' as a design principle. In this endeavor the concept was transformed from a means to compare institutions and technologies in networks to a method by which one can match institutions, as the mode of organization, to certain technologies, as critical technical functions. As such, the concept of coherence could provide the literature on the coevolution of institutions and technologies with a possibility to overcome its first mentioned obstacle.

The second obstacle will be explored by taking a closer look at theories on institutional evolution and coevolution itself in order to understand what governments should do when to ensure alignment. Special attention will go to the notion of cross-flows (Murmann 2003), causal linkages which transfer changes in technologies into stimuli for changes in institutions, and the fact that these cross-flows need to be the deciding factor among all the forces that make up the selection environment of institutional evolution for coevolution to occur. Key in this respect will be the presence or absence of a clear institutional best option fitting the technical changes and the 'radicalness' of the required institutional changes for alignment that shape the 'coevolutionary situation' at hand. A model is developed by which various ‘coevolutionary situations’ are equated with the amount of government intervention needed for alignment. With the help of the whole framework it can then be explored whether market forces are sufficient for institutions to coevolve or when and how much government intervention is required to align institutions.

In many ways the literature on coherence and coevolution fill each others gaps. Whereas the notion of coherence provides the method to find the mode of organization that needs to be aligned, a model on institutional coevolution to technical change gives insights in the problematique surrounding the alignment process. As such, when combined they may be able to create a framework for the pursuit of institutional alignment to technical changes as a policy objective. Hence this paper explores the possibilities and impediments of using the method of coherence and model for alignment to enhance or complement theories on coevolution in order to create a framework for the pursuit of alignment as a policy objective.

The paper is structured as follows. In the next section I address the existing body of knowledge on the coevolution of institutions and technologies at the hand of technical life cycles, identify the two obstacles, and elaborate on institutional evolution and how governments can influence it. The third section explores the concept of coherence by discussing the method to align institutions to technologies while the fourth section shows where possibilities and impediments to its use or addition to theories on coevolution lie. Section five then elaborates on coevolution in order to explore a model that allows for statements to be made about the government actions required to facilitate alignment. It will also be followed by an assessment (section six). Finally, section seven will conclude.

2. Framing the Coevolution between Institutions and Technologies

The creation of a framework for the alignment of institutions to technologies involves numerous building blocks. I propose to put them together in the following order. I start by defining coevolution, technologies and institutions. Afterwards, I take a closer look at the evolution of technologies, especially in terms of their market diffusion, and highlight the role institutions play in this regard to come to an account of coevolution. Then I put this account into its wider societal setting in order to complete it and frame the setting in which alignment is to take place. In the second part of this section I point to the obstacles or open ends of the account and switch attention to pursuing the alignment of institutions to technologies. To that end I discuss the evolution of institutions to see how technical changes might create pressures for institutional responses and discuss possible governance policies with which policy makers might pursue a policy of alignment. All in all, this section focuses on the existing body of knowledge and provides as such the starting point for the exploration of the possible addition of the method of coherence and the model for alignment.[1]

2.1. An Account of Coevolution between Institutions and Technologies

Coevolution is all about reciprocal interactions between two populations, entities or systems. According to Murmann (2003, 22 and 210), “two evolving populations co-evolve if and only if they both have a significant causal impact on each other’s ability to persist.” Similarly, Norgaard (1994, 26) defines coevolution as “relationships between entities which affect the evolution of the entities.” Moreover, Winder et al. (2005, 353) define coevolution as “interactions between evolving systems”, while they specify that these interactions need to be strong and in localized proximity (Kallis 2007, 2). Let me illustrate this at the hand of Kauffman’s (1993) example of coupled fitness landscapes. “In coevolution a la Kauffman,

[1] I label them *method* of coherence and *model* for alignment on purpose to distinguish them more easily.

one partner deforms the fitness landscape of the second partner and vice versa. As a result, a coevolutionary relationship between entities can increase the average fitness of both populations, decrease the average fitness of both, or have a negative or positive impact on the average fitness of one but not the other. Whether a coevolutionary process is beneficial or harmful for the parties involved depends on the particular causal relationship that links the parties; this relationship needs to be specified in [an] empirical analysis" (Murmann 2003, 22-23).

Both Norgaard and Winder et al. see in coevolution "a policy analytic, not a policy norm" (Kallis, 2007, 5). In essence, coevolution is a process, neither a priori something good or bad. "The goal is not to be able to adapt to changes whatever these might be. It is to decide which changes are desirable and try to approximate coevolutionary paths towards them" Kallis (2007, 5). Coevolutionary analyses serve to find possible causes, explore circumstances and to come up with policy responses. Coevolutionary analyses can also take the form of mental experiments on alternative futures and support making deliberate choices. As such, these notions help to conceptualize how best to pursue institutional alignment (which represents a policy norm or goal) using theories on coevolution.

The clarity of the definition of coevolution is unfortunately not present in those of technology and institutions. Although technologies are often intended as tangible artifacts, they sometimes also include ideas. To avoid such a difficult distinction, Saviotti (2005, 12) defines technology as "the set of activities by means of which human beings modify their external environment." In practice however, these 'activities' mostly come down to technical artifacts. A very basic example would be a car or internal combustion engine. A car for example allows us to engineer the physical environment by recreating our understanding of distance. He then identifies institutions in relation to technologies stating that "institutions are usually credited with establishing patterns of human interaction, by excluding some types of behaviour and encouraging others" (Saviotti 2005, 12-13). Beginning with North (1990), who defines institutions as "the rules of the game" and points to organisations as the players, several other definitions of institutions of Hamilton, Hodgson, Veblen and Loasby are discussed. In the end Saviotti states that all would be possible for use but that in relation to coevolution some additional considerations apply. He distinguishes four different institutions. First are institutions directly involved with the technologies such as firms. As these are hardly separable from technologies he rightly questions whether the concept of coevolution can be applied here: "the type of institutions that are directly modelled on particular technologies are hardly an interesting type of institutions. […] The most interesting part of the question is: what institutions other than those which directly produce the new technology can influence the mode and level of development of the technology itself" (Saviotti 2005, 13). This leads to the other three indirect institutions he identifies. These are regulating institutions, infrastructures, and institutions providing complementary inputs. Respective examples are, if one takes the car again as the central artifact, the coordination or governance of the technology like norms and standards and traffic management etc., the road and filling stations network, and complementary industries like tire companies, garages for maintenance, oil refineries etc.

If the focus were on technical systems however, not individual products but sets of technologies would represent technology. Good examples are infrastructures or networks where different technologies have to work together in order for the whole system to function. The technical 'artifact' investigated would then not only include cars, but also the car production and distribution companies, the road network and accompanying filling stations, the oil refining and distribution network, and tire factories and garages etc. As a consequence, the concept of technology is enlarged with the 'infrastructures' and the 'institutions providing complementary inputs' while only the regulatory or coordinating institutions remain as the concept of institutions. As such, institutions solely refer to governance. Or in the words of Koppenjan and Groenewegen (2005, 244), "institutions or institutional arrangements are […] a set of rules that regulate the interaction between parties involved in the functioning of a (technological) system."

Keeping these definitions of (sets of) technologies and institutions in mind, we can move on to their coevolution. A common starting point for analyses on the coevolution between institutions and technologies seems to be the industrial life cycle wherein technologies and markets coevolve from the emergence of a new technology to its maturity. It is this techno-economic paradigm against which the coevolution of institutions and technologies takes place. According to Saviotti (2005, 14) "the development of the institutions that are required to underpin the development of the technology itself has to be studied along the technology or industry life cycle." Although the life cycle was initially developed for individual products, Perez (2001, 114) states that "technological systems evolve along similar lines to those of individual products […]. New products [just] represent incremental improvements in the system." The life cycle is best described by Perez herself:

> "After a radical innovation gives rise to the appearance of a new product, capable of generating a new industry, there is an initial period of intensive innovation and optimization, until the product gains acceptance in the corresponding market segment. Interaction with the market soon determines the direction that improvements will take, and these often define a dominant design (Arthur, 1989; David, 1985). From that point on, as the markets grow, successive incremental innovations are made to improve the quality of the product, the productivity of the processes, and the producer's market position. This process culminates in maturity, when new investment in innovations begins to have diminishing returns. Depending on the importance of the product, the whole process can last a few years or a number of decades. In the latter case, the 'improvements' usually take the form of successive models" (Perez 2001, 114).

What is important to understand in such a technical and industrial life cycle is the difference between radical and incremental innovations and that generally four phases are distinguished.

In his 1982 work on technical change Dosi elaborates on the different natures of change (radical and incremental). He sees them as part of two different phases of technological evolution. Dosi (1982, 156) writes that the "economic and social environment affects technological development in two ways, first selecting the 'direction of mutation' (i.e. selecting the technological paradigm) and then selecting among mutations, in a more Darwinian manner (i.e. the ex post selection among 'Schumpeterian' trials and errors)."[2] This is basically a "logical distinction between the process of search and selection on new technological paradigms and technical progress along a defined path[3] [that is] likely to correspond historically to two different sets of features of an industry, related to its emergence and its maturity" (Dosi 1982, 157). Winter and Nelson further develop this idea claiming that "technological development often seemed to change in character as a particular technology 'matured' [also noting that] industry structure often seemed to change over the life of a technology" (Nelson 1994, 50). Indeed, firm and industry structures coevolve with technology. Perez (2001, 117) and Saviotti (1986, 774) also acknowledge this fact, the latter stating that

[2] As Dosi (1982) and Nelson (1994) noted that the economy or society sometimes selects directly among competing technologies (medical, military procurement agencies), sometimes however alternative technologies are incorporated within organizations in competition to each other in a multiplicity of selection environments.

[3] Saviotti points to the difference between product and process technologies where the former represents the inner core technology, the changing of which is radical, and the latter represents the additional technologies that responds incrementally to changes in the external environment.

"both the origin and the diffusion of technological change are greatly influenced by the economic environment in which they take place." This has led Klepper (1993) to investigate the opposite, that "the character of innovation is driven by changes in market structure, rather than the other way around" (Nelson 1994, 54). Consequently Perez and Freeman developed the notion of a 'techno-economic paradigm' rather than either a technological or an economic paradigm (Nelson 1994, 58).

Concerning the phases, generally four are distinguished based on the status of technological development and market diffusion. These are the R&D or invention and innovation phase, the early-market or imitation phase, the mass-market or competition phase, and the saturation or standardization phase. What makes the classification interesting is that each of the four phases has its distinct place in the evolution of a technology from its emergence to its maturity. This allows Murmann and Frenken (2006, 946) for example to further develop these phases in a more formal evolutionary model and label them: 1) technological discontinuity (variation); 2) era of ferment (substitution and competition); 3) emergence of dominant design (selection); 4) era of incremental change (retention and elaboration). This classification however hides a very different perspective. Note that while the two basic eras of radical and incremental change can still be distinguished, the phase of radical change differs from the life cycle presented above. Where Perez puts radical technical innovation in phase 1, as we saw earlier, Murmann and Frenken see radical change occurring when a new technology becomes the dominant design (phase 3). Only after a new technology has been selected as the dominant design does the era of incremental change begin. The difference follows from whether one studies technical change by itself or in relation to its market diffusion. From an exclusively technical perspective, the emergence of a new technology is the radical change and the rest merely incremental improvements. From a societal perspective, technologies represent breakthroughs once they have been widely adopted. It is this distinction which allows and even necessitates adding institutions to the life cycle framework. Whereas institutions are not needed as an explanatory variable in the technical perspective, they are very much considered an important factor for the rate of market diffusion of technologies in the societal perspective.

The clue to linking institutions to the life cycle lies in the fact "the creation of the institutions required for the further development of the technology occurs at particular phases of the life cycle." For example, Von Tunzelmann (2003) finds that changes in technology (product and process) and institutions (types of capitalism: market, hierarchy and network) have been alternating in response to each other since the industrial revolution. Where technologies develop under a specific set of institutions at first they in turn seem to generate a different set of institutions at a later stage in their development. Or as Saviotti (2005, 25) puts it, "there is clear evidence that technologies created in an initial form cannot diffuse beyond a very limited extent and that in order for their diffusion to proceed further appropriate institutions have to be created. […] Thus institutions will typically be created in the early stages of the diffusion of the technology and the extent of diffusion will be determined by the presence (or absence) of such institutions." Once one accepts the need for institutions for the development and deployment of a technology, it is only logical that the duration of that (set of) technologies' life cycle is dependent on the required time to construct the necessary institutions. However, there is more to it than that: the reciprocal influence between institutions and technologies does not end with the establishment of the institutions required by a technology. It continues throughout the life cycle of a technology. Yet it does so in a more incremental manner as the radical nature of change of the industry in its emergence is replaced by change within the range of the established technologies and institutions of a mature industry.[4] Finally he adds that Perez observed that the development of institutions was typically slower than that of technologies. Thus the four phases seem to create a particular pattern[5] in the coevolution between institutions and technologies. Whereas in the first phase technologies change radically under the existing set of institutions, in the second phase institutions change radically in response to the requirements of the new technology to function and develop further. Afterwards, when the new technology challenges the old in the market place, the interaction of the various actors involved (newcomers and established companies, scientists, governments and consumers) determines which technology prevails. They may also determine the dominant design if multiple new technologies challenge the old. Finally, if the new technology is successful and establishes itself, the new (set of) technologies seem to push for incremental institutional reforms (to the institutions created for the new technology in phase two) as the latter are easier to change than the artifacts already deployed, for example a pipeline network.

The general overview of the coevolution of institutions and technologies hides the fact that it is rather simplistic. Studies on socio-technical change highlight the concept of regimes within which both technologies and institutions mutually constitute themselves and point to the fact that new technologies and institutions do not emerge in full competition with the existing dominant institutions and technologies (regimes) but in protected market niches, altering the life cycle story. This implies that the alignment of institutions and technologies needs to be studied in a setting of the evolution of technologies (life cycle) and socio-technical regimes.

Literature on socio-technical transitions discusses how one socio-technical regime is replaced by another. Three levels are distinguished: regimes, niches and the landscape. Socio-technical regimes consist of “a set of technologies embedded in a social, political, and institutional context with its associated regime-specific set of rules, procedures, habits and practices” (Shackley and Green 2007: 223). What makes the regime work, are the actors linking the various technologies, markets and rules together. These can be technology suppliers (universities, R&D departments and knowledge institutes), industry incumbents (production, trade, storage, transmission, distribution and retail), government policy makers (federal, state, regional and local authorities, agencies), and private actors (consumers, public and private organizations). The interaction among technologies, institutions and actors is of great interest for explaining the development and diffusion of a new technology, the arrival of which is the starting point for a new socio-technical regime built around it.[6] The technological niche is the level where “new technologies emerge and some develop, protected from the full effects of competition with the dominant technologies in the socio-technical regime” (Shackley and Green 2007: 224).[7] The landscape level provides “the dominant assumptions, values and

[4] Like with technologies, the evolution of institutions can also be divided into radical and incremental change. This will be elaborated in section 2.2.

[5] It is the general perception that the radical and incremental change cycle of institutions is not simultaneous but alternates with that of technology. In reality of course both institutions and technologies are always constantly changing in response to each other. For reasons of understanding however I follow this general perception.

[6] A regime is dynamically stable; while the different technological, economic and institutional aspects are adjusted to each other, bringing the stability, they are also constantly changing within the range or context of the regime. However, the regime is quite inert to adapt to changes outside the discourse of the regime, hence the idea of system transition. Thus, it is at this level where “‘lock-in’ [and path-dependence] may take place, whereby technological regimes emerge alongside institutional and social changes” (Shackley and Green 2007: 223). The dynamic stability also implies that changes within the regime are of a more incremental nature whereas changes emerging outside of the regime force the creation of a new regime and hence have a more radical nature.

[7] Niches are important to test, on a small scale, the expenses, safety and reliability of innovations. They serve as incubators for radical novelties that have a “low technical performance, are often cumbersome and expensive” and operate under different performance indicators or selection criteria (Elzen et al. 2002: 13). Niches also create opportunities to construct social networks among (regime) actors that support specific innovations such as alternative and renewable energy technologies like hydrogen.

deeply rooted socio-economic trends at a given period of time" (Shackley and Green 2007: 222). This includes the key 'Weltanschauung' or philosophy behind policy-making and reflects "the dominant perception of 'problems' and the way to resolve those problems" (Shackley and Green 2007: 223).[8]

The relations among the three levels are characterized as one of a nested hierarchy. As such, niches are embedded in regimes and regimes in landscapes. Here, the socio-technical regime "accounts for stability of existing technological development and the occurrence of trajectories. The macro-level of landscape consists of slow changing external factors, providing gradients for the trajectories. The micro-level of niches accounts for the generation of radical innovations" (Elzen et al. 2002: 14). Within this context, innovation mostly occurs within the existing regime, and involves incremental changes towards regime optimization. This gradual pattern results from the interconnectivity of the various regime dimensions that allows only for small changes within the margins of the regime. However, "although gradual change is the common pattern, there are plenty historical examples of more radical transitions" (Elzen et al. 2002, 14), like the transitions from coal to oil and onto gas based energy systems. Here, novelties emerge and are developed in niches under the old framework - existing regime and landscape - often facing a mismatch with the established socio-political dimensions (Freeman and Perez 1988). New opportunities are typically countered by certain regime actors threatened by it. In both cases, "it is the alignment of developments (successful processes within the niche reinforced by changes at regime level and at the level of the socio-technical landscape) which determine if a regime shift will occur" (Kemp et al. 2001: 277). This shows the importance of the complementarity of institutional and technical change for a successful transition. What is more, the transition patterns are closely related to the four phases distinguished in the life cycle literature for the emergence of a new dominant technology is basically the path from a niche to a regime. Only now the phases are referred to as the pre-development phase, the take-off phase, the acceleration phase and the stabilization phase (Loorbach et al. 2008: 296).

Coming back to the coevolution of institutions to technical changes, it should be clear that it matters a great deal whether one conceptualizes coevolution with or without the dynamics of regime evolution. If included, one needs to rewrite the 'simple' coevolutionary pattern between institutions and technologies presented above. While technological change still occurs radically under the existing set of institutions, it generates not only new technologies, but also new 'niche regimes'. This implies that in the second phase institutions emerge (in response to the requirements of the new technology to function and develop further) within the new niche regime somewhat protected from the prevailing institutions of the dominant regime. Although the dominant regime's institutions still matter in the formation of new institutions for the niche, a possibility to avoid path-dependency and lock-in exists. Afterwards, when the new regime challenges the old in the market place, technological change is not only determined by actors' considerations of the effects of technical change, but of that of the whole regime, i.e. that of institutions as well. Finally, when the new technology

[8] These belief systems change very slowly and are hence often considered as the constant external environment or structure in which the socio-technical regime operates but its actors have no direct control over. To illustrate, "in our own society, the landscape is given by a concept of economic growth which has relied since the industrial revolution on fossil fuels, albeit with major shifts from coal, to oil and natural gas" (Shackley and Green 2007: 223). However, recently two trends have also started to shape the landscape level: institutional liberalization and increasing environmental awareness. Other important aspects are global fossil fuel scarcity and its geographical concentration, increasing energy demand, consumer preferences, demographic composition, level of urbanization, available technology, cultural characteristics, national specificities, migration, wars, etc. Changes at the landscape level can have profound impacts on the socio-technical regime as they can alter the rules of the game in which regime actors operate by changing the relevant goals and performance criteria and even by altering the perception of what is the appropriate or 'normal' way of doing things.

(regime) emerges as the dominant one, the issues surrounding inter-regime competition are no more. Now coevolution between institutions and technologies is 'simple' and takes exclusively place within the new regime.

2.2. Towards a Policy for Alignment

The account of technical life cycles and institutional coevolution is a mixed blessing. While it portraits the causation between technical and institutional changes nicely, it is not complemented by the knowledge "what types of institutions are required nor to what extent they can change the dynamics of creation and diffusion" (Saviotti 2005, 25). The opposite, how technical change affects institutions, or how governments can influence this process also remains unclear. Moreover, the above account creates the false image that technical change always leads to complementary institutional change. Institutions may coevolve to technical changes, but may also not do so. As we will see below, institutional change has many sources of variation besides technical, knows many pressures in its selection environment and involves a variety of selection mechanisms. They may lead institutional evolution in a different direction than alignment. This lack of knowledge was also noted by Nelson (1994, 61) who stated that formally modeling the coevolution of (supporting) institutions to the techno-economic paradigm is not an easy task due to two main reasons: a) it is not yet clear how various institutions can be represented; b) the (social) evolutionary processes involved in changing institutions are very different than those "built into extant formal evolutionary models." The former reason concerns matters such as what is meant by institutions and how one can operationalize them in such a way as to relate them to technologies. The latter reason urges asking how a coevolution process between institutions and technologies can be operationalized in order to understand what governments should do when and how to ensure alignment. To inform policy makers, we need to move beyond the descriptive and historical nature of research on coevolution so far and find a way to deal with these obstacles. To this end I will discuss the notion of coherence in section three and a model for alignment in section five. For now however, I will continue with how institutions evolve, how technical changes might influence institutions and how policy makers might influence institutional evolution to ensure its coevolution with technologies. I do this to separate clearly what is established knowledge on these matters from what is unknown and needs to be added to the framework presented in this section.

Influencing institutional evolution has two main aspects to it: first, it is about institutional evolution; second, it is about policy. Despite the large and well-developed literature on institutional evolution, I will restrict myself to the work of Campbell and Lindberg. What makes their model so interesting for the exercise of this paper is that they consider technological development explicitly as a possible pressure for institutional change. However, taking their perspective also implies focusing on governance regime as institutions. This is not an obstacle however if one recalls the definition of institutions of Saviotti and Koppenjan and Groenewegen in which the key institutions were those that pertained to issues of organization or transactions. As we will see in the section on 'coherence', this focus on governance regimes as institutions also fits nicely in the framework to be explored.[9]

In their 1991 chapter Campbell and Lindberg create an evolutionary model of governance transformation. In that model various sources for institutional variation are identified. These pressures are technical change, alterations in economic (efficiency) conditions, changing state

[9] The use of the concept of coherence narrows down institutions to modes of organization which is very similar to the idea of governance regimes. As this affects the entire framework the choice to focus on Campbell and Lindberg's governance regimes for institutions is actually very convenient.

policy, and the shifting of power and control among actors. The existing governance regime, culture and the wider political-economic conditions are considered constraining factors. In evolutionary terms, the first represents ‘retention’ while the latter two are larger trends shaping the market place (selection environment). Campbell and Lindberg distinguish between three kinds of actors (that link governance regimes to markets, i.e. the unit of selection with the selection environment): producer organizations (firms), other organizations (that typically respond to producers: suppliers, NGOs etc.) and state organizations. “Governance transformations are usually initiated by producers, but occasionally by other organizations, who respond to new problems and opportunities that are created by changes in economic conditions and technology. […] Actors do not respond automatically to pressures for change in a knee-jerk fashion, but rather select the ones, if any, to which they will react” (Campbell and Lindberg 1991: 329). In their actions, actors are contingent (bounded) rational agents (Campbell and Lindberg 1991, 327).[10]

“Three streams of action constitute the central dynamics of the selection process” (Campbell and Lindberg 1991, 330-331). First, producers initiate the search for a new governance regime. Second, these efforts are constrained by the strategies of other economic organizations, reacting to producers. Third, the state may pursue its own interests and strategies. This suggests an interactive process that involves trial and error learning, deliberate negotiations and cooperation, and coercion and struggle. “Of course, these complex interaction processes are mediated initially by the resources and power with which actors are endowed insofar as the strategies selected by powerful actors are more likely to be implemented than those of weak ones. […] The degree to which trial and error, negotiation and bargaining, or coercion prevail during the selection process determines, and is reflected by, the new governance regime that emerges” (Campbell and Lindberg 1991, 331-332). Hence, while there is no clear answer which of the three selection mechanisms will prevail in the process, it is clear that the nature of the selection process influences the outcome. As we will shortly see, it is here where possibilities for policy makers hoping to align institutions to technologies lie.

There are some things that should be briefly noted with regard to the account of institutional change as presented by Campbell and Lindberg. First, it is important to note that variation caused by technical development needs to be the main driver of institutional change throughout the selection process for coevolution to occur.[11] As such, all the other forces in the model need to be either absent, enhancing or marginally opposing the pressures that technical changes put on the direction of institutional change.

Second, while the model presented by Campbell and Lindberg gives a nice overview on the evolutionary processes involved in the emergence of a new governance regime, it neglects to elaborate on the difference between evolutionary and revolutionary change. It matters a great deal whether variation calls for a shift in the governance regime that fits in the existing paradigm or not. Actors may respond very different to paradigm change than to changes in the trajectory. The lessons from Dosi on technology hold true for institutions as well. Campbell and Lindberg state for example that actors sometimes react to new developments and sometimes not. Paradigm change is likely to affect their interests more than incremental institutional changes. Hence their role in the process tends to differ.

[10] “The elementary logic of such an explanation begins by recognizing that endogenous and exogenous forces episodically disrupt production and exchange. In response, actors search for solutions to this disruption through a series of complex decisions in which economic, organizational and political choices that were institutionalized in the most recent governance regime limit the options that are currently available to actors during the search” (Campbell and Lindberg 1991, 328).

[11] This point will be elaborated at the hands of the concept of cross-flows in section 5.1.

Third, the model seems to implicitly cling to two core drivers: one of optimization of institutions to technology and/or economic circumstances; one of power and politics. Campbell and Lindberg for example state that “economic signals and technology are not usually decisive in determining specifically the direction of change or the outcomes of governance transformations.” They continue that “because governance transformations involve significant changes in a governance regime’s structure of rights, rules, and compliance procedures, these matters are of intense, often strategic, interest to most actors” (1991, 328). Künneke et al. state something similar in their account of institutional evolution (2005, 1-20): they take the optimization of transaction costs as the main driver behind institutional change that produces cycles of evolutionary and revolutionary change and limit the role of vested interests to stopping or supporting occurring events.

Finally, the second and third point can be combined: in phases of incremental change, conditions are such that matters of economic efficiency seem to take preference over social and political goals, while during phases of radical change it is likely to be the other way around. This is likely because in phases of incremental change, vested interests support the institutional changes as they optimize efficiency to their own benefit. In revolutionary phases the necessary institutional response is disputed. The optimization of institutional arrangements is likely to necessitate a new paradigm or set of assumptions that undermines vested interests. As such, a cycle of alternating radical and incremental changes can be imagined. Radical change occurs when highly optimized institutions (to specific settings) are confronted by an external shock that cannot be accustomed within the existing set of institutions. Incremental institutional change in turn occurs when optimization takes place.

The state of knowledge surrounding policy for influencing evolutionary processes is best described as ‘very close, but just not there yet’. This is because only two out of the three relevant questions have been answered. The questions where to intervene and how to intervene have been answered and will be discussed below. The question when to intervene however remains unanswered. An attempt will be explored in section 5.

Regarding the ‘where’, the key for policy makers to influence institutional evolution and pursue coevolution lies in the selection process. Let me elaborate on this point by looking at the setting for a coevolution between governance regimes and technologies in formal evolutionary jargon. If we take the governance regime as the unit of selection that needs to align to technical changes and policy makers as the actors that link the creation of new institutions to the market place (the selection environment, which itself is a product of larger political economic and cultural trends[12]), we can start framing the setting in which alignment is pursued in. In this case, retention is the existing governance regime (and the actors’ positions and interests therein), while variation is caused by new technical opportunities that (might) require institutional reform to function properly. Selection finally takes place in the selection environment and involves all relevant actors (the various government, business, scientific and public actors) and selection mechanisms identified by Campbell and Lindberg. In this setting government policy makers can only hope to influence the selection process; the rest has to be taken as given from the policy makers’ perspective. This is simply because retention represents what is, which of course cannot be altered any more, and variation is already given in the form of technical changes that require specific governance regimes.[13] Moreover, government ability to influence the selection environment is limited at best. Although actors may reshape the structure of which they are part over the long term, at a specific point in time it is very much the structure that conditions the possibilities of actors.

[12] As such it is better to speak of the selection environment as a ‘socio-politically embedded market’.
[13] If it were not for the goal of alignment however, governments might try to influence both the variation and selection process, i.e. the development and diffusion of new technologies, to ensure coevolution.

Moreover, in a market economic setting, government influence over society, trends and other actors in the selection environment is already limited. The latter will have their own interests regarding the technical and institutional changes and will pursue them just as policy makers will. As we will see below, the lack of ability to influence the selection environment only enhances its role as a key determinant for in how far technical changes will become stimuli for institutional change. As such, influencing the selection process itself represents the main possibility through which governments can influence institutional evolution.

Regarding the 'how', the three interaction processes of Campbell and Lindberg (trial and error, negotiations and cooperation, and coercion and struggle) can be seen as governance paradigms that can be chosen by governments. In general, policies to influence policy processes are classified rather standard according to the amount of government intervention in the market. A good example of this is presented by Arentsen et al. (2001, 11) who distinguish between three basic policy packages[14] when it comes to stimulating green innovations: facilitating, initiating and enforcing. Whereas the former entails supporting the selection of green innovations, the latter two entail the encouragement and forcing of the selection of green innovations respectively. Similarly, the four governance paradigms differentiated by Hisschemöller et al., based on whether the major actors collaborate or compete in either a public or market setting when it comes to the governance of an energy transition to hydrogen, might also be considered in this regard. Of course, these examples involve policies to stimulate technical innovations; but this does not imply that the same can not be done for institutional reforms. To illustrate: the similarities between Arentsen et al.'s policy packages and Campbell and Lindberg's interaction processes are obvious. Where hands-off or market approaches have similar effects on selection as the mechanism of trial and error and facilitating policies can be added to that mechanism, and where initiating policies and public-private partnerships are similar to bargaining and negotiation, public approaches based on enforcement are similar to coercion. Of course there might be more distinguishable categories. The point is, whether in Campbell and Lindberg, Arentsen et al., or Hisschemöller et al., the interaction processes, policy packages or governance paradigms all aim to set the environment in which innovations or institutional reforms take place. As such, they enable and constrain certain options and hinder others. Or in evolutionary jargon, they influence the selection process. In the end, the interaction processes of Campbell and Lindberg provide for basic governance paradigms at the disposal of government policy makers. However, these paradigms, like the "policy packages of interrelated and mutually reinforcing strategies" of Arentsen et al. (2001, 11) act as a set of possible strategies only. It is not further specified when which strategy should be applied. Hence there is no link between the strategies and 'coevolutionary situations', for the lack of a better concept. Hence if I wish to progress on aligning institutions to technologies I need to link sets of policies to coevolutionary situations. To that end I will go deeper into theories of institutional evolution and coevolution in section 5.

3. Matching Institutions and Technologies

In a number of recent studies, Finger, Künneke and Groenewegen (2005 - 2008) found that the economic, social and technical performance of infrastructures is dependent on the "degree of coherence between the technical and the institutional coordination" (Finger et al. 2006, 13). They showed, for example, by analyzing infrastructures before and after institutional liberalization, privatization and deregulation that the performance differed because institutional changes were not matched by technological ones. In a liberalized setting "the

[14] These policy packages involve a number of specific policies and policy foci regarding the structure, conduct and performance of technical, economic and institutional dimensions of promoting green innovation.

infrastructure business is decomposed into regulated and commercial components that are forced to operate independently from each other. Under these conditions, there is no economic or other incentive to optimize the system's complementarity" (Finger et al. 2006, 4). At the same time the technical operation of the infrastructure still requires this complementarity to ensure the proper functioning of the whole. "This results in a very paradoxical situation" (Finger et al. 2006, 4). Thus where the institutional coordination of networks has become decentralized, market oriented and is guided by private values, the technological coordination has remained to a large extent centralized, top-down organized and guided by public values. As such, non-matching institutions and technologies affected performance.

Considering the difficulties coevolutionary scholars have in comparing institutions and technologies, one needs to ask just how Finger et al. could arrive at such a clear conclusion? The answer lies in the concept of coherence that they have developed. Let me explain this by first addressing their approach to technologies and institutions and then their way of comparing and matching both.

3.1. Critical Technical Functions of Networks

Finger et al. (2006, 4-5) start of characterizing infrastructures as physical networks that link various industries along the supply chain with each other and with consumers. Safeguarding technical system integrity hence becomes an important priority. Technical integrity "implies a need for the capacity of the overall system to correct errors or unexpected outages of network elements in a way that operations can be maintained, at least in parts of the infrastructure." Without network integrity the production and allocation of a technology or product simply cannot take place. In addition, to ensure the functioning of the infrastructure the various nodes and links, i.e. the industries and network, need to work together in a certain order to produce the desired end-product. "Typically, nodes and links cannot be used at random, but need to be approached in a coordinated way in order to produce a specific service" (Finger et al. 2006, 4). Both in turn necessitate some form of technical coordination that aligns and governs the technical operations within the network and facilitates system complementarity. Thus, "from a technical perspective, this coordination is very elementary to safeguarding the functioning of the system." Since coordination depends on the technical specificities of the network, it can be assumed that different networks require different technical coordination.

Finger et al. (2006, 11-12) distinguish between four technical functions that can be considered critical [15] for safeguarding the technical complementarity and functioning of networks: interoperability, interconnection, capacity management and system management. Interoperability focuses on the "mutual interactions between network elements" and as such "defines technical and institutional conditions under which infrastructure networks can be utilized." Issues raised for example are the complementarity between trains and tracks, natural

[15] In their 2008 article, Künneke et al. define the concept of technical criticality in infrastructures as "those aspects of the technical operation and management of any given infrastructure that are critical in order to meet expectations with respect to the technical functioning of these systems" (Künneke et al. 2008, 4). This entails first specifying the expectations with respect to the technical functioning of infrastructures. Doing so they define reliability, safety and security of supply, where the focus then turns to reliability only. Then one needs to find ways how to identify those aspects of the technical operation and management of infrastructures that can be considered critical in regard to the expectation of reliability. Special attention goes to the defining characteristic of infrastructures: strong technical system complementarities. Here two aspects are discerned that determine the criticality in infrastructures: a) critical assets and b) "specific functions that are essential to safeguard the technical performance of infrastructures" (Künneke et al. 2008, 5). The former are assets fundamental to the functioning of a technical system. They are more tangible objects like traffic control systems in railroads, transmission lines in electricity or pumping systems in the water sector. Künneke et al. focus however more on the second notion, the technical factors of criticality.

gas and pipelines etc, but also issues like the harmonization between the purity of natural gas produced with the specifications of applications. Interconnection deals with the "physical linkages of different networks […] As such, interconnection is closely related to the technical system boundaries." Gas pipelines often exist as local distribution networks but also exist as part of wider national and continental transmission networks. In railways there is also a similar difference between various national networks and international or high speed networks. Capacity management concerns the allocation of "scarce network capacity to certain users or appliances." Issues pertain to the operational balancing and strategic and tactical operation. Questions about the scope and capacity of the network, who should get access, the facilitation of actual access and the daily operational management of the technical flows through the network are addressed. Finally, system management "pertains to the question of how the overall system (e.g. the flow between the various nodes and links) is being managed and how the quality of service is safeguarded." This often comes down to aligning supply with demand, both in quantity (over and under supply and consumption) and quality (preferences on goals such as affordability, availability, reliability and perhaps in the future 'renewability').

In order to facilitate the proper functioning of the four critical technical functions control mechanisms need to be established that monitor important performance parameters. After a brief discussion of closed control systems[16], the authors match their definition of technical criticality with the characteristics that closed control systems point to. Thus they identify control mechanisms as critical if they imply a) a significant technical scope of control and are unique (no alternative control mechanisms exist that perform similar tasks) and b) strong time constraints (Künneke et al. 2008: 9). In other words, the criticality of the four technical functions is determined by the scope of control and time constraints.

3.2. Modes of Organization of Networks

We saw that the technical functioning of an infrastructure is dependent on the complementarity of its parts and that in this respect some coordination of the overall system is required. The next question becomes what institutions there are to govern technical functioning. To understand infrastructure governance Finger et al. look at the school of New Institutional Economics because it pertains to how "specific types of transactions can best be coordinated in specific types of governance structures." In doing so, Finger et al. show that the governance of networks is strongly determined by economic and socio-political factors.

New Institutional Economics (NIE) focuses on transaction costs - and not production costs like classical economics. Transaction costs refer to the costs incurred when using the price mechanism / making an economic exchange. They involve such costs like finding information about products and markets, drafting and upholding contracts etc. Institutions are crucial in this respect because they can reduce transaction costs. By providing an operating framework for economic exchange, institutions such as rules, regulations, standards and procedures address property rights issues, reduce risks and create transparency, which in turn decreases costs. According to that logic institutions are driven towards the minimization of transaction costs just as markets are driven towards production cost efficiency. In NIE it is all about what is the optimal governance structure to minimize transaction costs is given the institutional environment of values and norms, given the preferences and attributes of the actors, given technology and given the broader political and legal structures. In this endeavour, governance structures are not only an issue of private ordering. Because of specific characteristics of

[16] "Closed control systems are characterized by a feedback loop between the actual and desired performance and the ability to adjust system performance in case of intolerable differences between both" (2008, 7). In contrast, open control systems are "based on the assumption that the relation between input and system performance is sufficiently stable to satisfy expectations, while ensuring the technical functioning of the system" (2008, 6).

infrastructures like the collective good character of network industries, natural monopolistic features of networks, network externalities and the public values / national interests that are related to them, market failures occur necessitating government intervention. Both contracting and organization therefore play an important role in the governance of networks.

What decides then whether the governance of networks should be private or public? Basically, "economic actors replace markets for hierarchies by integrating transactions into the hierarchy (vertical integration) when it is efficient to do so, i.e. when transaction costs are lower" (Finger et al. 2006, 5). NIE points to a number of factors that together map the characteristics of a transaction: asset specificity, uncertainty and opportunities for strategic behavior (frequency of transaction). The specific mix of these factors determines whether a market oriented approach (contracts) are best suited or whether government intervention (organization) is more efficient in terms of transaction costs. When asset specificity increases, risks become bigger and opportunities for strategic behaviour increase (or frequency decreases), transaction costs rise and organization is increasingly more efficient. In other words, "market contracts are suitable for transactions that do not demand complex negotiations between parties, whereas hierarchies refer to transactions that are highly complex and which call for complicated negotiations" (Finger et al. 2006, 5). This is to say that simple transactions allow actors to include all uncertainties into a contract (which is then able to provide solutions and dispute settlement for all eventualities), while complex transactions do not allow for that, hence becoming inefficient in coordinating actors and necessitating vertical integration.

In their articles Finger and Künneke adapt these insights from NIE to networks and operationalize them further. Special attention in the governance of infrastructures goes to the mode of organization of institutional arrangements. This is similar to the notion of governance regimes that was discussed by Campbell and Lindberg. Künneke et al. (2008, 235) are interested "in modes of organization that guarantee the coordination of transactions related to critical technical functions of liberalized infrastructures". The mode of organization is operationalized along a divide between hierarchical integration (top-down, centralized, public orientation) and autonomous market processes (bottom-up, decentralized, private orientation) with various intermediary modes in between. The institutional framework is operationalized as ownership (private or public), the level of vertical integration, the regulatory framework (competition policy or sector specific) and the market structure (monopoly, oligopoly, competition) (Künneke 2008, 22; Finger et al. 2006, 3). The mode of organization shapes the institutional arrangements according to a public or private logic opening up a variety of possibilities to govern an infrastructure. The rest is rather self-evident: a private mode of organization implies private ownership, a horizontal organizational structure, competition regulation and a competitive market setting while a public mode of organization equals public ownership, vertical integration, sector specific regulation and a monopolistic market structure. Surrounding a private approach is a general focus on competition, profitability, an international and local orientation, shareholder control and market prices while a public approach is embedded in a sphere of public values, political controllability, a national orientation, government control and regulated tariffs (Künneke and Fens 2006). Of course, the two ideal-types are not likely to be found as clearly separable in reality as they are in theory. Indeed, existing networks often involve elements of both types. Yet while Künneke et al. distinguish between the public and private ideal type modes of organization and recognize the various possible intermediary modes that lie in between, they do not further specify these modes. Instead they rely on case studies of various network industries to provide for the nuance. As each network has its own technical and organization specificities, they need to be studied in-depth to see what mode of organization of the institutional framework exists.

3.3. Comparing and Matching Institutions and Technologies

Now that we have identified technologies and institutions as critical technical functions and modes of organization respectively, the next step is to compare them. Here the notion of critical transactions comes in. Where transactions are defined as the "transfer of 'rights to use' goods or services across technically separable interfaces" (Künneke et al. 2008, 11), critical transactions are those transactions that are essential to accommodate critical technical functions. The authors distinguish two dimensions that make up critical transactions: "a systemic dimension, which relates to the technical scope of control and the speed of adjustment of critical technical functions; and an organizational specific dimension, which concerns the organizational needs to meet the technical system requirements" (Künneke et al. 2008, 12). Concerning the former, Künneke et al. distinguish between twelve modes of organization based on three scopes of control and four time spans indicating the speed of adjustment necessary to perform the feedback loop in closed control systems.[17] It can be stated that on a very general level "the coordination requirements become more stringent the larger the technical scope of control and the shorter the time period to react on disturbances" (Künneke et al. 2008, 13). Depending on technical conditions, "the need for coordination can be accomplished through different modes of governance, including the implementation of standardization, different types of contracting, or even market competition for the best suitable technical solution" (Künneke et al. 2008, 13). Concerning the latter, there are "critical effects related to the way the economic viability of the system is organized. […] In other terms, there are organization specific effects which are as essential as systemic effects to deal with in order to assure performance that allow the system to work" (Künneke et al. 2008, 14). Here insights from institutional economics shed some light. As we saw, asset specificity, uncertainty and opportunities to strategic behavior (frequency) shape the organizational mode best suited to the transaction at hand. As a result, complex modes of organization emerge. In the end, "both the systemic and organizational dimensions should align in their coordination of critical transactions with critical functions, pushing either towards integration, so that a unified organization secures the requirements of criticality, or towards hybrid arrangements, with a strategic center coordinating parties that are simultaneously complementing each other and competing" (Künneke et al. 2008, 14-15). In other words, the mode of organization necessitated by the critical technical functions is equated with the mode of organization necessitated by the economic viability of the system. The key to the comparison lies in the relation that higher levels of criticality in the technical dimension (technical functions) match with more top-down governance approaches of the organizational dimension (economic transactions) while lower levels of criticality in the four functions match a more bottom-up approach guided by market forces. A mismatch hence occurs when the technical and institutional dimensions are not both governed by the same approach or mode of organization. Of course, 'coherence' exists when they match.

Künneke et al. (2008, 14) use the notion of critical transactions to compare the systemic and organizational dimension of infrastructures. The last step that remains is then to switch from a comparison to one of aligning institutions to technologies. During such an exercise, a different logic applies. Now, we can assume that technologies are given while the economic or institutional dimension can be considered non-existent or free for interpretation. This creates the opportunity to optimally design the mode of organization of the organizational dimension according to the technical dimension's requirements. As such the concept of coherence does not only provide for the means to compare institutions and technologies with an eye to performance, it could also serve as a guideline for policy formulation. After all, governments

[17] These are the system, subsystem and component level for the scope of control and the very short term, short term, medium term and long term for the speed of adjustment.

could use ‘coherence’ as a design principle to actively change the mode of organization to fit a certain technology in order to remedy governance mismatches. The method for aligning institutions to technologies follows from the comparison and is worked out in Künneke et al.’s 2008 article.[18]

Künneke et al. present a step-wise progression from technological characteristics to the critical technical functions of infrastructures, then identifying the critical transactions that should facilitate the former in order to derive the mode of organization of the institutional framework.[19] Key in this respect play the three scopes of control and four speeds of adjustment of the systemic dimension. They can be combined with each other, resulting in a matrix of twelve combinations that classify the criticality of technical functions. In addition, we need to remember that Künneke et al. distinguish between two ideal types of modes of organization, one public and one private while they recognize the various possible modes that lie in between. What links the twelve combinations to the modes of organization is that each one of the combinations represents a specific set of transactions in terms of asset specificity, uncertainty and opportunities to strategic behavior. As these sets of transactions represent what is required from an organizational point of view to ensure the functioning of critical technical functions, i.e. the critical transactions, they can in turn be translated into modes of organization. The ‘logic’ between the systemic and the organizational dimension remains the same: transactions become more critical the larger the scope of control and the shorter the necessary speed of adjustment of critical technical functions, while higher levels of criticality necessitate more hierarchical modes of organization (in contrast to more market oriented approaches to organization for lower levels of criticality). For example, when a technical function needs to be addressed in the very short term and involves system wide operations, the combination results in a mode of organization of authorative supervision. Another example would be a technical function that involves the medium term on the component level that requires a competitive allocation mechanism as mode of organization. The technical functions and accompanying transactions of different infrastructures are hence implied to vary in their criticality.

4. Assessing the Use of the Method for Coevolution

In the introduction I asked the question in how far ‘coherence’ can contribute to the alignment of institutions to technologies, i.e. realizing coevolution in a transition to new technologies or technical systems. As we have seen, the notion of coherence allows for both comparing and matching of institutions and technologies. This would immediately solve the first obstacle to a policy of alignment. However, there is more to it. First, the use of ‘coherence’ is conditioned by the fact that it applies to networks or technical systems and not the individual products so often described in theories of coevolution. Second, the use of ‘coherence’ also necessitates applying its definition of institutions and technologies to the wider coevolutionary setting in

[18] It needs to be recognized that the mode of organization here is optimal according to technical characteristics only and not economic considerations. The latter are not considered because they are expected to be modelled according to the technical requirements themselves. Hence it is not about the comparison between economic organization and technical functioning, but about matching institutions to technologies. Such an exercise can be characterized as comparative static, for when the matching mode of organization has been found we would essentially have calculated an equilibrium to which we could formulate a policy in the sense of reforming governance structures to match technical requirements. It is very important to note however that the process of how to get to the equilibrium is not investigated.

[19] Obviously, the most difficult step in the stepwise progression and the key to matching lies in the step from critical technical functions to critical transactions, and represents the core addition of ‘coherence’ to scientific understanding. The other steps, moving from technical characteristics of a network to the critical functions and moving from critical transactions to the mode of organization, are already dealt with in literature on technical systems and NIE.

which it is used. Third, because sets of technologies may function with different networks and these are likely to require different modes of organization, to which should the method be applied? For example, a possible use of hydrogen as a motor fuel allows for onsite hydrogen production, tanker trucks and pipelines as distribution networks. Fourth, because the four different technical functions may have varying degrees of criticality, even within one network, how is one to combine the various resulting modes of organization into one working whole? Fifth, the method does not provide an exact measurement of just how much market and government is required. Some further operationalization is still needed. Finally, as 'coherence' is a static comparative approach[20], it does not solve anything about the second obstacle that relates to achieving coevolution or executing a policy of alignment in a dynamic setting. Of course, it was never intended as such. Yet, transitions to new technical systems can imply the build-up of different networks at various moments in time or phases of the transition; how can such a process be incorporated? Summing up, while the first two points might be inherent to the use of 'coherence' as a design principle and hence cannot be altered or helped, the latter four can. Let me discuss these in turn.

Concerning how one can match institutions to technologies when a set of technologies would allow for multiple networks: can there be any modelling with such variety? The method can only find a mode of organization for a single network. For the application of the method to be feasible one needs to have a clear view on what constitutes the core technology. A solid analysis of which networks suit best to national characteristics might narrow down the variety to manageable proportions and might make taking a decision easier. This could also mean one would have to choose which network to focus on.

A somewhat similar issue arises when the criticality of the various technical functions differs so greatly that an overall mode of organization that matches all functions becomes difficult to find. How to deal with this? One possibility is to focus on the technical functions that are most critical and leave those who are not out of the equation. It is likely that they can be left to the market anyway as they are less critical. Another option is to consider devising a mode of organization per critical technical function instead of the network as a whole. The sum of the parts then makes up the governance of the infrastructure. In the end, this seems more a conceptual desire rather than an actual problem. The point is not to create an overall mode of organization, but to ensure technical functioning.

Next, the measurement of the exact nature of the public private divide is not as straightforward as it may seem. As was indicated, Künneke et al. distinguish between twelve modes of organization. Although the direct border of these modes might be distinguishable in theory, matching network functions to one of these modes of organization is not an exact science in practice, just as classifying transactions in NIE retains considerable room for debate. Technical functions may for example require multiple scopes of control and may have overlapping speeds of adjustment. This creates difficulties for the justification of the modes of organization perceived as matching. In this sense it might be wise to focus on just a few general modes of organization that are more distinguishable than current twelve. One possibility is to operationalize the modes of organization based on whether the network is owned and operated either publicly or privately. This allows for a matrix of four modes of organization that represent various levels of criticality. For example, a market based approach exists when both the ownership and operator are private while a public approach exists when both are public. More interesting are the two modes in between. On the one hand there is the combination of government ownership and private operation which would represent the

[20] Please remember that when 'coherence' is used to match institutions to technologies, it only points to how the mode of organization should be and does not make statements on how to get there.

current regulatory approach. On the other hand, private ownership and public operation would constitute the category of a public private partnership in which private parties are responsible for executing policy but do so under some form of central coordination. Of course this is only a suggestion and has not been explored properly yet.

Regarding that the method of Künneke et al. provides only a snapshot of the optimal mode of organization for technical functioning at a given moment in time, how to use it for a process to new technical systems? The key to institutions complementing the technical changes in a transition involves applying the method developed by Künneke et al. to each of the four phases of the technical life cycle discussed in section 2.1. This means distinguishing which technologies will be developed and deployed when and using the comparative static method to find the optimal governance structure befitting the technological system existing in each of the four phases.[21] This exercise could be aided with examples from similar current networks. Putting all the static images together, a roadmap emerges. The differences in the necessary modes of organization (and institutional arrangements) between the phases then account for the institutional reforms required when moving from one phase to another. Considering the dynamic nature of a roadmap, important questions that arise are whether institutions and technologies are likely to coevolve and whether emerging incoherences, as the result of a lack of coevolution in the shift from one phase to another, can be 'set right' in a shift to the next phase. Other interesting questions are whether there will be a shift in criticality along the four technical functions mentioned; for example that in the early stages of the emergence of a technological system issues of interoperability and interconnectivity are more critical while later, when the network is mature, capacity and system management issues become more urgent.

By and large, the concept of coherence provides us with a real possibility to overcome the first obstacle to creating a framework for a policy of alignment, at least to the extent that the conditions are acknowledged and the impediments are overcome.

5. Towards a Framework for Pursuing Coevolution as a Policy Objective

Knowing which institutions match technologies is one thing, being able to reform institutions to align them to technical changes is quite another. Although institutions are affected by technical change, so they are also by numerous other forces as we saw in the discussion of institutional evolution by Campbell and Lindberg. Hence, institutions may sometimes respond to technical changes and sometimes not. If complementary institutions are the objective, government action to rectify may be necessary. In any case, to pursue the alignment of institutions to technologies as a policy objective, governments need to know what they should do when to ensure alignment.

To find out I explore the concept of cross-flows and its relevance for attaining coevolution with the help of insights on coevolution and institutional evolution. Central in this endeavour will be the ease with which cross-flows linking changes in technology to institutions will be able to effect complementary institutional changes in various 'coevolutionary situations'. As we will see, this has much to do with the presence of clear institutional requirements and the radicalness of the required institutional changes for alignment. In addition, these coevolutionary situations will be linked to the governance paradigms[22] needed to ensure

[21] One can determine the hypothetical optimal mode of organization for a future technical system as long as one knows that system's technical features, i.e. the supply chain of the infrastructure.

[22] I name these paradigms of governance deliberately so as to distinguish them from the governance regimes or modes of organization discussed in earlier sections.

coevolution in them. A model or hypothesis will be built around the idea that when the clarity of the institutional requirements decreases and the radicalness of the proposed institutional changes for alignment increases, cross-flows will have a more difficult time spontaneously creating coevolution, increasingly necessitating government intervention for alignment. The aim is to create a framework on how in specific situations governments can best pursue institutional alignment as a policy objective.

5.1. Coevolution, Cross-flows and Obstacles

As we have seen, coevolution is all about the reciprocal interactions between two populations, entities or systems. According to Murmann (2003, 22 and 210), "two evolving populations co-evolve if and only if they both have a significant causal impact on each other's ability to persist." Core to coevolution are 'cross-flows' or causal relationships that link institutions and technologies. They facilitate that changes in the evolution of one system (technological) affect the evolution of another system (institutional).[23] Cross-flows come in a variety of forms. Examples are contacts between the actors of a socio-technical regime allowing them to exchange information, expertise and ideas or the invisible hand of the market forcing actors to behave in a certain way. This way technical problems and needs can be translated into pressures for organizational action. Investigations of coevolution usually need to clearly establish the precise mechanisms through which cross-flows connect two systems because not everything that looks like coevolution is coevolution. "As Nitecki (1983) points out, coevolution may be mimicked by such things as sequential adaptations from different causes or simultaneous adaptation to the same environment" (Murmann 2003, 23). In this paper however, the point is not to prove that coevolution took place or study the exact nature of cross-flows but to analyze when governments[24] should and how they could influence institutional evolution by facilitating cross-flows. What policies should be deployed when to ensure coevolution?

The major obstacles to cross-flows from technologies to institutions are other forces in the selection process of institutional evolution. As we saw, the actors selecting new governance regimes exist within and are influenced by the wider selection environment and not just technical changes. Campbell and Lindberg distinguished for example four other sources of variation for institutional change next to technical change. Moreover, they pointed out the constraining force of retention and identified culture and broader political economic trends that shape the selection environment, selection criteria and constrain actor behaviour in the selection process. Indeed, the concept of bricolage comes to mind here (Campbell 1997). As a consequence the influence of cross-flows from technology to institutions competes with the influences of other forces. This in turn implies that institutions and technologies do not necessarily evolve by themselves in a similar direction; although technologies and institutions interact, both also are subject to many other societal forces (actors and factors) that influence their evolution in a variety of ways. As such, they need not automatically coevolve; a transition policy might be needed that facilitates the alignment of institutional evolution to technological changes. The question arises to what extent technical changes are able to alter the course of institutional evolution through cross-flows, creating 'true' coevolution. This harks back to the definition given to coevolution by Winder et al. when they talk about that the interactions between evolving systems need to be 'strong' and 'in localized proximity' (Winder et al. 2005, 353); Kallis 2007, 2). Darwin and Murmann (2003, 11-12) also acknowledge this aspect when they state that when one looks at evolution of a species it is not

[23] Other authors refer to 'matching agents' (von Tunzelmann, 2003) or 'translations' (Grin et al. forthcoming).
[24] By assigning governments this role in institutional evolution I implicitly acknowledge that institutions can be designed. Here I follow the work of others who believe that institutions can and need to be designed to come to efficient outcomes (Finger, Groenewegen, and Künneke 2005; Koppenjan and Groenewegen 2005).

about identifying all forces that influence the evolution, but at the one (or few) core forces that ultimately determine the direction where a species is evolving to. Hence Norgaard states that "coevolution is not only about 'co', but decisively about evolution" (Kallis 2007: 1).

The discussion of cross-flows and their obstacles forces us to realize some things. First, cross-flows are operating in very different 'coevolutionary situations' (for the lack of a better concept) depending on the amount and severity of obstacles. Second, different coevolutionary situations require different policies for alignment to occur: coevolution can take place spontaneously, but can also be in need of facilitation. This highlights two points of attention that need to be addressed if a model for a policy of alignment is to be created. First, how to classify coevolutionary situations and relate them to appropriate policy responses for alignment? Second, how to distinguish between coevolutionary situations, i.e. how to know which situation applies? I will now deal with these questions in turn.

5.2. Spontaneous Coevolution and Designed Alignment

In order to make statements on how governments can best pursue the alignment of institutions to technologies as a policy objective, I need to identify situations of coevolution and link policy options / governance paradigms to them. To this end, I propose to do three things.

First, I differentiate between spontaneous coevolution and designed alignment. We just noted that different amount of obstacles or forces shape different kind of coevolutionary situations and in turn required different policies. When linked to the governance paradigms identified at the end of section 2.2 a certain logic starts to become clear. Two extremes can be imagined. On the one hand coevolution can occur spontaneously because the cross-flow from technologies to institutions might face few obstacles or counter forces in the selection process. In such a case, pressures for institutional change emerge bottom-up out of society (market forces and actors) and only require policy makers to respond. A policy for alignment based on a laissez-faire market approach (trial and error) would suffice. On the other hand, the same cross-flow might meet considerable resistance and would not be able to affect the direction of institutional change. In such a case, the government should step in to rectify if alignment is the aim. This however requires a much more active attitude in order to facilitate alignment. Top-down design and control might be needed. In terms of the policies identified this would be coercion or enforcement. Of course, there exist various intermediary governance paradigms. The facilitating and initiating policy categories of Arentsen et al. still remain for example. Before moving on, let me clarify that I take the government as an entity that actively pursues the goal of alignment, but will do not more than is necessary. That is to say when market forces of trial and error are sufficient to produce the desired institutions policy makers need merely respond to societal pressures, whereas if market forces are unlikely to be sufficient policy makers need to act. They will do so in varying degrees by 'rigging' the selection process. As such, governments only act when needed.

Second, I need to find a way to differentiate and classify coevolutionary situations. I believe that a good starting point for such an exercise lies in the two views on what determines the course of institutional evolution. As we saw in the discussion of Campbell and Lindberg, on the one hand market forces determine the direction of institutional change because they push towards the optimization of governance regimes to a specific setting. On the other hand, it is the social setting in general and the interests of the most powerful actors in particular that determines the direction of evolution. It was also noted that both tell part of the story. Whereas optimization represents an incremental but ever-present force, actor interference represents a more decisive but occasional force. With regard to finding coevolutionary situations, these two views allow for the identification of four possibilities. On the one hand institutional variation caused by new technologies can be divided into two possibilities: there is one clear best organizational match for the technologies and there are multiple, disputable matches to best govern a technology to ensure its functioning. It is important to note however that a clear best option can of course exist in a setting full of inferior alternatives; the best option need not be the only option. On the other hand, institutional selection can be divided into two possibilities from a government's perspective: whether the required institutional changes for alignment are considered favourable to or will upset the existing order. This implies grouping all evolutionary forces in the selection process[25] into one variable on whether societal actors support or are against the proposed institutional change(s). Put differently, will existing power structures and institutions and larger socio-economic trends make actors favourable towards the required institutional changes or not? Combined, a two by two matrix can be imagined that represents four possible combinations between the clarity of the required institutional response (clear or not) and the support for required changes among actors (support or not). The combinations then represent coevolutionary situations that are in essence based on the obstacles to cross-flows mentioned earlier.

Third, I propose to link the governance paradigms to the four coevolutionary situations. Basically, different combinations of clarity and support require different policy responses to ensure alignment. Let me now elaborate these links. I will deal with them in turn starting with the combination that requires the least action, i.e. where coevolution is the most spontaneous, and ending with the situation requiring most government design. Finally, the possibility for parallel evolution is briefly addressed. It needs to be clarified that for the purpose of this exercise I have assume that the technical changes are supported by all actors. Otherwise there would be no change in the first place to which institutions need to be brought into alignment with.

Coevolution is supposed to emerge spontaneously in a situation in which there is a clear best institutional response or governance regime[26] for the technical changes and the actors (the direct institutions or firms adopting the technology in the definition of Saviotti) adopting the technology are supporting these institutions. In this situation market forces push for the appropriate governance regime. New technologies might alter production processes which in turn involve different economic transactions and which require different forms of governance. There might also simply be no other way to govern the technology. In addition, there is societal consensus on the direction of the required changes, that is to say it is either not a sensitive issue or that the economic and political consequences are beneficial for the actors involved. In this setting pressure for the complementary institutional changes hence comes from society, i.e. the market and the actors. Policy makers need only to respond to the outcome of the selection process. They need not interfere in or steer market forces in their execution of the selection mechanism of trial and error.

Coevolution can also be expected to emerge spontaneously in a situation where there exists no best institutional response but the actors involved do support a specific governance regime. The fact that the institutional requirements remain unclear or are debatable implies that market forces do not push for a certain governance regime. Yet because actors still support a specific direction of change similar pressures as before urge the government to respond and facilitate the desired institutional changes. In a way, the lack of a clear best governance regime has failed to create (groups of) supporters for different governance regimes so that

[25] This includes all sources of variation, the characteristics of the existing governance regime (retention), the selection environment (market), the cultural and political economic trends influencing the selection environment, and the interests and power bases of the various actors.
[26] Looking at section 3 the term mode of organization could be used here just as well.

consensus is maintained. In reality this seems rarely the case. There usually simply exist too many parties and interests.

Alignment is expected to require government design in a situation where there exists a clear best institutional response to technical changes but where actors do not support it. This is a difficult situation. While the market pushes towards a certain governance regime, vested interests try to hinder such a development. If alignment is the aim, the government now has to ensure that the best institutional response will prevail among the various possibilities likely to be proposed by the other actors with views to the contrary. It is therefore likely that some coercion and struggle will be required to ensure alignment. In this sense this situation is the most difficult for a government to pursue alignment in. However, the last option will be the most difficult to get alignment as a result.

Alignment is also in need of government intervention in a situation in which there exists both no clear best institutional response or support for any (specific) option. The multiple possibilities to govern a new technology now have led to divergent views on how to govern it. Basically, the cross-flow from technology to institutions has failed to make an impact on institutional evolution. As there exist many parties with each promoting equally sound governance regimes in terms of technical functioning, i.e. there exists no support for a single option, the government cannot do more than step into a process of negotiation and bargaining to ensure that a satisfactory decision is reached and not many divergent modes start to exist. This has two problems. First, how to decide what institutions should be? With the absence of a best option there is basically no legitimacy to place one above others, i.e. for the government to select and force one option. Second, there is a big risk that no decision is taken at all. In a way, nothing happens. This means no coevolution.

Finally, it needs to be recognized that coevolution might not be required for the goal of aligning institutions to technologies. A parallel evolution might also occur. In this case cross-flows would be either non-existent or only marginal forces in the evolution of institutions, but institutions would align to technologies anyway because of the pressures of other evolutionary forces. Complementary institutions are hence not a product of coevolution or designed alignment but simply emerge independently: basically various different forces in the evolution of institutions and technologies create an outcome similar to that of coevolution. Although a long shot, the possibility cannot simply be neglected.

Table 1 Linking coevolutionary situations to the governance paradigms required for alignment

Variation and Selection	Clear best institutional response	No best institutional response
Actors support change	Spontaneous coevolution where government needs only respond	Spontaneous coevolution where governments facilitate changes
Actors do not support change	Designed alignment where government decides and forces	Designed alignment where government negotiates as party

To sum up, the four situations defined and the possibility for parallel coevolution create a framework in which institutional alignment can emerge spontaneously or needs to be designed as a policy objective. This in turn implies that governments can achieve alignment through different means. Spontaneous forces necessitate little more than a government that reacts to societal pressures while they would need to actively pursue institutional alignment when actors oppose the expected reforms towards a best governance regime. The next question then becomes what holds when: when can alignment be expected to be spontaneous (emerging from cross-flows) and when is design needed?

5.3. Market Forces or Government Intervention

Above I argued that how governments can best facilitate institutional alignment (what they are required to do) depends on whether the forces in the selection environment allow the cross-flow to be decisive in charting the direction of institutional evolution. The next question then becomes how to know which of the four coevolutionary situations is occurring at a given point in time. How to know whether there is a clear optimal governance regime and support for that option by actors; and to what extent? Considering that the first question can be answered by the concept of coherence (does it allow us to find one best option or not), only the latter remains to be answered. In order to understand actor support for change in general and for the appropriate governance regime in particular we need to open up the concept of 'actor support' previously conceived as the aggregate of various evolutionary forces. In other words, we need to study it in its full complexity in order to derive at a well-balanced assessment of the gravity or 'radicalness' of the implied institutional changes. In this regard, the most prominent obstacles to a situation of spontaneous coevolution are the following.

First, the variation caused by other forces than the changing technology also pushes for an institutional response. A conflict arises between aligning institutions to technical specificities and other economic, political, cultural and social drivers or forces. If the variation caused by changes in technology creates less pressure for institutional change than other sources of variation then obstacles to spontaneous coevolution arise. Second, the embeddedness of the existing institutional arrangements conditions the future options of institutional change (retention). The required governance regime might deviate strongly from the current. It also matters whether the current institutional framework is highly specialized towards a specific set of technologies. Tightly coupled systems tend to have higher performance, but lower flexibility when it comes to adjusting to new situations or radical changes. Third, trends in the selection environment of institutions might contradict those of technologies making it difficult for cross-flows to link technological change to institutional change. It also matters how strong a regime or institutional arrangement is with respect to resisting outside pressures. Fourth, the prospect of the emergence of new institutions brings changes that suit the interests of some while it hinders the interests of others. In response, the latter actors will try to influence policy formulation and decision making processes in order to move selection away from complementary institutions. Summarizing, these four general matters hinder the emergence of coevolution through market forces, necessitate government intervention, and need to be resolved if governments want to play a constructive role in facilitating coevolution.

Apart from these evolutionary forces, it also matters in which phase of a transition to a new technology the situation is located and to what extent established innovation patterns and policies can temper radicalness. Concerning the phases of a transition to a new technology, we need to recall section 2.[27] There we saw that the relationship between new technologies and their institutions develops over the life cycle of a technology, most notably being that new institutions emerge and develop within the new niche regime but do so under a set of existing institutions. Later the institutions of the niche regime compete with the institutions of the old regime when the technologies start to compete for market share. Finally the institutions respond to technical changes within the new dominant regime incrementally without the hindrance of old regime's institutions. The four phases hence differ greatly in the gravity of the implied changes and the processes and actors involved in these changes. For example, finding an optimal governance regime for a technology is likely to be easier when a dominant design exists. Before that multiple technical options are likely to confuse. Another example is

[27] To remember: phase 1 saw radical technical change, phase 2 saw radical institutional change, phase 3 saw regime or socio-technical change, and phase 4 saw intra-regime dynamics only.

that the interests of actors and the power relations among them shift over time as new technologies gain market share while older ones lose out. Hence vested interests might not always be triggered into action. In addition, larger trends or changes in the selection environment might not always be able to affect a governance regime equally. Mature regimes might be more able to resist outside pressures. Finally, retention is likely to play a more restrictive role before regime change than after. Concerning the innovation pattern, Van de Poel noted in his article on the transformation of technological regimes (2003) that in some (network) industries radical innovations (in technology) are more acceptable or commonplace than in others and therefore expected and accepted. Industries tend to be more flexible in this regard. Although it remains to be seen whether this also holds for institutions (governance regimes), it is an interesting concept nonetheless. Campbell and Lindberg already pointed out that actors maybe sometimes more inclined to action than in other times. Perhaps issues such as environmental urgency or EU unbundling decreases (effective) resistance to change.

Summing up, by looking at the evolutionary forces surrounding institutional change, the phase in which they occur and the innovation pattern, the 'radicalness' of the proposed institutional changes can be assessed. Together with the outcome of the method of coherence the coevolutionary situation can be determined. Hence we now have the tools to estimate whether spontaneous market forces will be sufficient for coevolution to emerge or when government intervention is needed. For reasons of clarity, let me formulate a central hypothesis and restate the variables that ultimately determine the outcome as a list of questions per phase.

Hypothesis: when the clarity of the institutional requirements decreases and the radicalness of the proposed institutional changes for alignment increases, cross-flows will have a more difficult time spontaneously creating coevolution, increasingly necessitating government intervention for alignment.

On the presence of a clear best institutional match:

- Is there a clear optimal institutional option or dominant design to the technical changes?

On radicalness of required institutional changes:

- Variation
  - Are there many other sources of variation rivaling the cross-flow from technologies to institutions?
  - Are the causes of technical variation endogenous or exogenous to the existing regime?
- Retention
  - Are the required institutional reforms within the logic of existing institutional arrangements?
  - Is incorporation of changes likely to be easy and/or along the expectations of the reform process?
- Selection environment
  - Are incentives in the selection environment favouring a shift to a new governance regime?
  - Are the institutional framework and regime strong enough to withstand these forces or pressures?
- Selection
  - Are vested interests or newcomers likely to benefit from the institutional changes?
  - What is the influence and involvement of the various actors on the selection process?

The combination of the hypothesis and the questions effectively create a model for the alignment of institutions to technologies. After all, investigating these questions in detail will provide for an overview of the forces influencing institutional evolution and its coevolution with technology (radicalness), an overview of whether a market-driven development is likely to achieve coevolution or when government intervention is necessary (coevolutionary situations and policies), and an overview of differences in prospects for coevolution between phases. This also allows for speculating how the process, being either left to market forces or government policies, could predetermine the outcome. Amidst these promises, it of course needs to be restated that this still is a hypothesis that has to be thoroughly tested.

6. Assessing the Use of the Model for a Policy of Alignment

In the introduction I asked how governments can pursue the alignment of institutions to technologies in a transition to new technologies or technical systems as a policy objective. By looking deeper into theories on coevolution and highlighting the role of cross-flows a model on the presence of a clear best institutional match and the radicalness of the required institutional changes for alignment to the technical changes and their relation to the amount of government intervention required was established. Nevertheless, some issues may be noted as possible drawbacks to the hypothesis / model for alignment.

First, the model requires a clear perspective on which technology or technical system should have complementary institutions. Approaches on possible future technologies that leave all options opens will not be able to incorporate the model because they fail to isolate one (set of) technology to which institutions need to be aligned. Second, it also requires an idea of what the institutions need to be, i.e. what needs to be aligned. As the method of Künneke et al. is the only way to assess that, the model is also bound by the method's focus on sets of technology or networks. Third, further operationalize of the evolutionary forces involved is required to come to indicators that allow to assess radicalness properly. Yet even if successful, much will still be up to speculation. Just how far into the future can the model be used? Talking in terms of the phases of technical, institutional or regime change, while it may be possible to recommend a general policy for the step to the next phase, phases further in the future may become increasingly estimation. Where one knows the situation in t and can derive prospects and policy for t+1, one does not know the situation that will actually come at t+1 that is necessary to assess prospects and policies for t+2 etc. Fourth, while the simplification of evolutionary selection processes into two categories with each two possible outcomes is comfortable for deriving a workable hypothesis, it might prove too simple to do justice to the complexities of institutional change. Finally, the model of alignment did not take into consideration what policy makers actually can do, instead focusing exclusively on what they should do. In remains to be seen for example just in how far governments can switch from one governance paradigm to another.

7. Final Comments

In the introduction I stated that the literature on the coevolution of institutions and technologies was not able to assist policy makers in setting up policies that aim at aligning institutions to technological changes. Two obstacles were identified: there exist no means to compare and match institutions and technologies and there was no means of knowing what governments should do when to influence coevolutionary processes in such a way as to facilitate alignment. This paper then investigated the method of coherence developed by Künneke et al. and explored a model for alignment in order to deal with the two obstacles. When combined with the existing body of knowledge on the coevolution of institutions and technologies they may be able to create a framework for the pursuit of institutional alignment to technical changes as a policy objective. The aim of the paper was to see in how far the method and model represent possibilities to do so.

The paper finds that while the notion of coherence is valuable in overcoming the obstacle, it also narrows the scope of the application of the framework to its definition of institutions, technologies and network industries. Next to that, it was argued that the four problems associated with ‘coherence’ – how to deal with network variety, combining various modes of organization into one, the difficulties surrounding measurement of criticality and its static comparative nature – can be overcome. The model to derive policies for alignment seems promising but faces difficulties in application to situations further into the future and neglects what policy makers actually can do focusing instead on what they should do exclusively. Next to that the model requires a clear view on the technologies that need institutional alignment and is bound by the possibilities and impediments of the method of Künneke et al. in this regard. Finally, the simplifications necessary to be able to derive at a workable hypothesis allows only capturing general coevolutionary situations. All in all, the combination of the method and model proves an interesting possibility to fill the gaps of the literature on coevolution that warrants further investigation.

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