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Integrating path dependency and path creation in a general understanding of path constitution. The role of agency and institutions in the stabilisation of technological innovations

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Abstract

Path dependency as it is described by Arthur and David portrays technological developments as historically embedded, emergent processes. In contrast, Garud and Karnøe's notion of path creation emphasises the role of strategic change and deliberate action for the development of new technologies. In this article, we integrate both concepts into a general understanding of path processes which accounts for emergent as well as deliberate modes of path constitution. In addition, we distinguish between three consecutive phases of technological path developments. Both conceptualisations are used to create an analytical grid against which empirical cases of path processes can be matched. Based on this general understanding, we further outline how concepts from science and technology studies and institutional theory can help to elaborate the role of deliberate action and emergence in the stabilisation of technological paths over time.

1 Introduction

The message of path dependency appears to be simple: once you're on you probably can't get off. First developed to describe technological developments (David 1985; Arthur 1989), such a reading of path dependency is now widely understood as a plausible argument to describe inertia, stability, and irreversibility in a broad range of contexts (see Mahoney 2000; Greener 2002; Ackermann 2003; Beyer 2005). The broad application of path dependency has also inspired discussions of some of its underlying ideas, like contingency and non-ergodicity (David 2001), as well as critical notions like mindful path creation (Garud/Karnøe 2001). In this paper, we will limit ourselves to the analysis of technological paths and will not discuss the literature on institutional, political or historical paths or other forms of path dependency. We would like to contribute to this specific discussion by revisiting key concepts from path dependency, relating them to later ideas about path creation, and adding ideas about agency and institutions for our conception of path constitution.[1]

For this purpose, we suggest that the reference to technology in the original concept of path dependency as it was made by David ("technological interrelatedness") and Arthur ("competing technologies") should be taken seriously. At the same time a broader – primarily sociological – theoretical framework is needed in order to explain the development of technological paths. This article explores how the innovation of technologies can be understood as a process that is shaped by emergent processes which are more or less beyond the control of actors, as well as by active engagement, i.e. mindful contributions of powerful actors. We draw on the established concept of path dependency in order to account for emerging stabilities and seek to expand its scope by invoking the more recent notion of path creation (Garud/Karnøe 2001) to allow for elements of strategic change and deliberate action. In order to bridge the gap between the two perspectives on path processes, we aim for a general understanding of path constitution which does not describe emergence and deliberate action as contradicting explanations, but looks towards describing them as two ends of a continuum. Subsequently, a general understanding of path processes as showing properties of both emergence and deliberate action lends itself towards an elaborate description of different technological innovations.

In chapter two, we first revisit the general conceptual ideas of classic path dependency reasoning and then refer to the recent concept of path creation. Following this brief discussion, we integrate these two analytic frameworks into a broader concept of path constitution. The analytical framework of path constitution is mainly intended to provide an informed perspective in order to distinguish between multiple empirical cases of technological developments. In chapters three and four we then argue for the incorporation of more elaborate models of agency and institutions into the concept of technological paths. We do so by referring to concepts from science and technology studies (STS) and new institutional theory. With our discussion of agency and institutions we especially seek to further our understanding of the processes of stabilisation at work in the constitution of technological paths. We conclude with a summarising discussion of our general understanding of

[1] This paper is based on Uli Meyer's ongoing dissertation research on the innovation of Advanced Driver Assistance Systems in the automobile industry and on Cornelius Schubert's work in the research project "Path-Creating Networks: Innovating Next Generation Lithography in Germany and the U.S.", funded by the Volkswagen Foundation and supervised by Jörg Sydow and Arnold Windeler. Previous ideas have also been published in a working paper (Meyer/Schubert 2005).

path constitution, pointing out its key characteristics as well as sketching out further issues that should be discussed in more detail.

2 A general understanding of path constitution

2.1 Path dependency

David and Arthur developed the path dependency concept to propose a market diffusion model of technology which takes into consideration the historical embeddedness of economical processes. Instead of assuming technology to be optimal by definition, as it is done by neo-classical economic theory, the dominance of certain technological designs is explained by historical processes. Efficiency is not seen as the central reason for technological developments, therefore technologies are not expected to be optimal in every case.

The path dependency concept describes technological developments as being sensitive to initial conditions and influenced by processes which are probabilistic in nature. Triggered by *small events* (Arthur 1989: 118), inconspicuous random differences in the beginning of a development can lead to very different results later on. Such small events can be, for example, unexpected external incidents or the sequence in which new buyers choose between competing designs of a new technology. Because of the massive impact such small events can have, technological success is described per se as unpredictable.

This unpredictability however is only true for the emergence of a new technology, i.e. before a technology becomes a quasi-standard. Once a technology is established, the development becomes predictable or even irreversible. This is caused by *increasing returns* (Arthur 1989: 116) which manifest in a variety of processes. If increasing return processes are at work in the development of a specific technological design, every advance of this specific design leads to further advances. Certain developments, once started, grow stronger out of themselves. Arthur for example mentions "learning by using", "network externalities", "scale economies", "informational increasing returns", and "technological interrelatedness" (1988: 591).[2] In this way, a small advantage in the beginning probably leads to the total dominance of one design. Accordingly, further diffusion of this technology is not just predictable but also irreversible.

In case a technological option becomes irreversible by virtue of increasing returns, a technological path is *locked-in* (ibid.: 334). David assumes that only *external shocks* (2001: 26) can change a technological path, once it is locked-in. In line with path dependency's probabilistic reasoning, a lock-in occurs without any actor planning it. It merely emerges over time because of small random events at the beginning of a new technology design and the increasing returns, which were triggered by these events.

Especially Arthur has developed elaborate formal mathematical models to describe this idea of technological stabilisation as being sensitive to initial conditions and emphasised the probabilistic properties of such processes (1989). Behind these reduced formal mathematical models of path evolution, technological development is seen as something very complex. It is not goal oriented, it is not reversible, it depends on uncontrollable events, and

[2] The idea of increasing returns again contrasts with neo-classical theory, which is based on the assumption of decreasing returns. In contrast to increasing returns, they allow to making predictions based on mathematical models. Accepting increasing returns to be an element of economic processes results means the end for a lot of micro-economic forecasting models. This is one reason why the path dependency concept met heavy opposition in the beginning (Waldrop 1992).

there are many mechanisms which can lead to increasing returns and lock-in. But despite this perspective on technological development as being extremely complex, the concept is based on problematic simplifications:

1. Actors are thought to behave rationally in the sense that they always choose the technology which is best suited for them. However, technological paths are the result of an emergent evolution behind the backs of the actors.
2. Also, increasing returns and lock-in are emergent processes, which are not and can not be the result of deliberate planning and mindful action.
3. Once a path is locked-in, only external shocks can break it.

Subsequently, we suggest that several notions of the path dependency concept require modifications. Increasing returns, for example, is too narrow a definition of a more general phenomenon: self-reinforcing mechanisms. It is not just economic forces which stabilise an emerging path but social ones too. In addition, it is disputable if a lock-in can ever be as complete and irreversible as Arthur assumes it to be. A more general weakness of the concept is the very simple actor model. On the one hand, the only relevant actors are buyers who are conceptualised as fully rational individuals. On the other hand, actors are not considered to influence the shape of the competing technologies – at least not in the formal models. That is not a satisfactory perspective taking into consideration, for example, the enormous efforts companies undertake to promote their own standards and technologies (for a discussion of VHS winning over Betamax, see Cusumano et al. 1992).

In general we see the elegance of path dependency as argued by David as well as Arthur in the use of neo-classical assumptions about the individual actor to describe processes that can not be explained by neo-classic economic reasoning, e.g. the persistence of suboptimal technological solutions. David and Arthur point out that suboptimal technological solutions do not emerge due to a lack of individual optimal choices but because of them, and that this is especially true in conditions predicted by market economics. However, the mechanics of increasing returns rely on a relatively stable market structure. Otherwise the described increasing-return mechanisms would not work. This only explains path dependency if technology is introduced into such a stable frame of reference, e.g. a consumer market filled with profit-optimising actors, but it says very little about the initial condition of choice in which the technologies themselves are shaped. In terms of Arthur, these conditions are reduced to mere chance processes like small events, with no actors having control over them. This reduction can not sufficiently grasp the complex interrelations and agency of artefacts, collectives of actors, and institutions in organised innovation processes.

2.2 Path creation

The concept of *path creation* by Raghu Garud and Peter Karnøe (2001, 2003) offers solutions for some of the problematic simplifications of path dependency. On the one hand, it is based on the same fundamental assumptions: technological development is historically embedded, it may stabilise and – if this happens – it is hardly reversible. On the other hand, and in contrast to path dependency, probabilistic events are not assumed to be the primary explanation for technological path development. Instead, the authors stress the relevance of strategic, deliberate and mindful *action* of actors. Actors initiate the development of a path through *mindful deviations* from known procedures or rules (Garud/Karnøe 2001: 6). Mindful deviation is not a solitary act, but a long lasting process of continual path creating and stabilising activities. For ex-

ample, the development of the post-it notes lasted for more than ten years before the path was actually stabilised.

In their articles of 2001 and 2003, Garud and Karnøe give two very different examples of path creation: the development of the post-it notes at 3M, and a comparison of wind turbine development in Denmark and the US. In the case of the post-it notes, they describe how the discovery of a "glue that does not glue" (ibid.: 14) leads to the development of the well known post-it notes. The authors focus on the role of actors in shaping an emerging path, especially on Spencer Silver, the "creator" of post-it notes, who mindfully deviated from 3M's routines of developing stronger kinds of glue. Borrowing concepts from Actor-Network-Theory (ANT), they describe, how he managed to "mobilize" different resources like "minds", "time", and "molecules".[3] In contrast to the empirical examples presented by Arthur and David, they also focus on the pre-market phase of the innovation. The path of the post-it note is created before the product is introduced into the market.

In their second empirical study, Garud and Karnøe (2003) compare the development of wind-turbines in Denmark and the United States. In contrast to the strong emphasis of the individual entrepreneur in the post-it example, Garud and Karnøe stress the mindful, yet emergent, character of technological development. They describe "entrepreneurial agency as distributed across multiple actors" (ibid.: 277). The path is stabilised by the accumulation of inputs from multiple actors who can influence, but never fully control the process. They portray the two different countries as examples for different strategies to establish a technological path: bricolage in Denmark and breakthrough in the US. Bricolage describes the emergent co-shaping of technology and actors. There were no grand plans regarding what wind turbine energy production was supposed to look like in the end. Rather, distributed actors offered inputs to generate a virtuous learning circle. Breakthrough, in contrast, describes long-term planning in combination with a competitive market structure. Because of the latter, and the resulting lack of cooperation between central actors, a stable path did not develop in the case of the US wind turbine industry.

Garud and Karnøe emphasise, that a path can be the result of deliberate strategic activities of a multitude of actors. Nevertheless, it is not guaranteed that the path is in any way consistent with the intentions of the actors responsible for its development. They refer to Giddens' structuration theory to emphasise that the developing path is medium and result of the activities of actors at the same time (ibid.: 281). Thus, the problematic simplifications of the classic path dependency concept are addressed by highlighting the deliberate aspects in path creation:

1. Powerful actors can strategically influence the development of a path. They can shape the path, while over time they are themselves shaped by the path.
2. Increasing returns and lock-in are subject to deliberate actions and tied in with broader social dynamics.
3. The creation, but also the ending of a path may be caused by deliberate actions which do not necessarily have to be external.

However, path creation says very little about the development of a technological path after it has been created and the question remains how the two conceptual approaches can be inte-

[3] Because of the extensive application of the term "mobilizing", it is used to describe such different things as "mobilize a collective to identify 'a problem for his solution'" (mobilizing minds: Garud/Karnøe 2001: 14-18) or "apply [the glue] directly to paper" (mobilizing molecules: Garud/Karnøe 2001: 13-14).

grated into a general understanding of path constitution.

2.3 Path dependency vs. path creation?

The central difference between path dependency and creation is the particular understanding of a path's constitution (see Table 1). Arthur and David emphasise the relevance of emergent and non-intended consequences of actions and the stochastic properties of the resultig processes. In contrast, Garud and Karnøe stress the deliberate influencing of technological developments through powerful (collective) actors. The following gives an overview of these properties.

The merit of the path dependency concept is *first*, the refusal of the assumption of technology as always being selected by the market on grounds of efficiency as described in neo-classical economic theory and *second*, the theoretical embedding of technological development in its historical context. This is an important step towards a general socio-economic explanation of technological innovation. As a *further* step, path creation adds to this a more elaborate concept of actors and their role in technological development, as well as an understanding of the broader social dynamics in which the development of a path is embedded. Here, we would like to add to the discussion by first pointing out some aspects which deserve further clarification:

1. How can the interplay of evolutionary emergence and strategic deliberate action be adequately described in a general understanding of path processes?
2. How can such a general understanding of path processes be enriched with sociological concepts that go beyond the simplified actor model of classic path dependency reasoning?
3. How can path processes be distinguished from any other forms of stabilisation over time?

In the following, we present a general concept of path constitution which combines the advantages of the path dependency and path creation concepts. Based on this, we attept to give some preliminary answers to the first question in the remainder of this chapter. We will address the second question in chapters three and four of the paper and, last but not least, deal with question three in our conclusion.

2.4 Path constitution

In order to obtain a more general understanding of path processes in technological innovations, we suggest that the concepts of path dependency and path creation should be combined into one concept of *path constitution* which

Table 1: the basic properties of path dependency and path creation

	Concept of constitution	Path properties
Path dependency	<u>evolutionary-emergent:</u> Paths emerge behind the back of actors, they are not and cannot be controlled by them.	- History matters - Increasing returns - Lock-in
Path creation	<u>strategic-deliberate:</u> Paths can be deliberately created by actors, if they are able to mobilise the necessary resources.	- History and social actors matter - Increasing returns and mobilising actors - Lock-in

takes into consideration both concepts of path development so that paths can be seen as a mixture of emergent processes and deliberate actions. In our concept we distinguish between two analytic dimensions: modes and phases of path constitution. The modes of path constitution can be used as a sensitising concept for differentiating between the emergent and the deliberate aspects of path constitution, where the phases of path constitution provide us with a simple grid for classifying aspects of emergence and deliberate action within a temporal order. We see the modes and phases of path constitution as analytical distinctions, not as ontological facts, and only use them a) to describe the constituting elements of a path in greater detail and b) to analyse empirical cases more precisely.

Modes of path constitution

The respective conceptualisation of path constitution, both in path dependency and path creation can be seen as the two ends of a continuum. On the one end are emergent completely unplanned processes, and on the opposite end are deliberately and strategically controlled processes (cf. Windeler 2003; Sydow et al. 2004). In the analysis of a concrete empirical case, one has to determine at which point between completely unplanned and completely controlled processes the analysed case is situated. At one extreme of this continuum, the constitution of a technological path is the result of an entirely emergent process, without being planned at all. David's now classic example for this is the emergence of the QWERTY-keyboard.[4] Close to the other extreme of path constitution we find examples which are the result of planned processes, like large technological projects initiated by national governments, e.g. the sponsorship of nuclear energy.[5] More in between the two extremes, we find processes in which the actors do not have full control over the development of the path but are aware of it, and influence it to a certain degree through deliberate actions.

There are different reasons why a path may be only partly controlled. One reason is that the relevant actors do not have the resources necessary to control its development to a higher degree. Or maybe actors just do not want to spend more resources on the control of a path. But in contrast to pure emergent processes, the actors are aware of the development of the path. They observe it, calculate the chances of success in regard to different possibilities, and use their resources to influence the development if they think it is worthwhile. Actors therefore may "bet" on the success of one path. It can also occur that actors bet on more than one of different competing paths, thus "hedging their bets" which especially accounts for large companies with sufficient funds who partake in various competing strategic alliances (cf. Linden et al. 2000). Also path processes may exist, where the direction of the path is the emergent result of deliberate actions of different actors, but the result was not intended by any one of them, e.g. in case of conflicting or competing perspectives.

Phases of path constitution

The development of a path can – analytically – be divided into different phases: generation, continuation and termination. *Generation* describes processes from the beginning of a path until it has stabilised. When a path has become stabilised, the phase of *continuation* begins which may then end

[4] This is at least true for the description David provides (1985). We assume there is a high probability that also for this case one could at least find some deliberate attempts, e.g. from the company which introduced this specific keyboard design, to stabilise it.

[5] Of course there are – as the example of nuclear energy clearly shows – limits to such planning.

in a phase of *termination*. This distinction is necessary for integrating path creation and path dependency into our general understanding of path constitution. Also, it is useful for distinguishing different empirical cases.

The *generation* of a new path can have different causes which correspond to different types of processes between the two poles of emergence and deliberate action. For this phase of path generation, it is therefore useful to distinguish between the modes of *path creation* (resulting from deliberate actions) and *path emergence* (resulting form chance and small events). But one thing is crucial: irrespective of how a path has developed, after it has stabilised, and positive feedback has set in, it is very likely to become locked-in. For this, it is irrelevant whether the path emerged as in the case of the QWERTY-keyboard or if it was created by deliberate actions as in the case of the post-it-notes. An example of this is the post-it case itself, where Silver and the other actors managed to establish the post-it note as a product which represented a useful application for their "glue that does not glue". During this process, the path they created became stabilised and now continues more or less on its own.

The phase of *continuation* in case of the post-it notes shows all features of a path as described in the concept of path dependency. First, there are positive feedback loops, which stabilise the path even without any support of the original creators. Today, the development of post-it notes has its own logic detached from the reason why it once was created.[6] Because the phase of continuation in both cases – post-it and QWERTY – shows the same features, it seems to be useful to apply the same term for both. We propose to use the term *path persistence* for this mode of a path continuation. This is a deviation from the usual coinage of path dependency, but we think it is nevertheless useful to do so because the concept of path dependency should be a general feature in the description of stabilised paths. Therefore, we disconnect the question of how a path was generated – whether emergent or strategically planned – from the properties of a fully developed path itself. On the other hand, it might be the case that a technological option does not become locked-in by its own virtue but has to be continuously stabilised by deliberate actors. The mode of *path extension* accounts for the mindful contributions that can keep a technological option dominant by organising sustained support from the relevant actors. In contrast to path creation, there is no mindful deviation from existing structures but rather a mindful continuation of an existing path. This requires that actors are aware of the path and have actively decided to support it. However, once the phase of continuation is reached and the process is more or less path dependent, it displays some sort of self-reinforcement.[7]

But this does not mean that a path will continue forever. Even after lock-in is reached, different kinds of further developments are possible. If, for example, a path comes to an end, we speak

[6] Two available post-it notes products exemplify this point very clearly. The first are the so called "super-sticky-notes", which have much "stickier" glue than the regular ones. This is a useful product out of a "post-it note logic", but if you consider post-it notes as an application for "glue that does not glue", it is quite absurd. The same applies to "post-it digital notes", a computer programme which allows you to "stick" notes on your computer desktop. So today, the idea even works without a material basis and without glue.

[7] Nevertheless, the issue remains that if we look for stabilising effects beyond the mere economic notions of increasing returns, the social and technical processes will not display simple mathematical mechanisms but must be seen as versions of stabilisation much like "technological paradigms" (Dosi 1982) or the "Matthew effect" (Merton 1968).

of *path termination*. If the termination is mindfully created by actors, we would describe this as deliberate *path breaking*. If it results from emergent processes, we call it *path dissolution*.

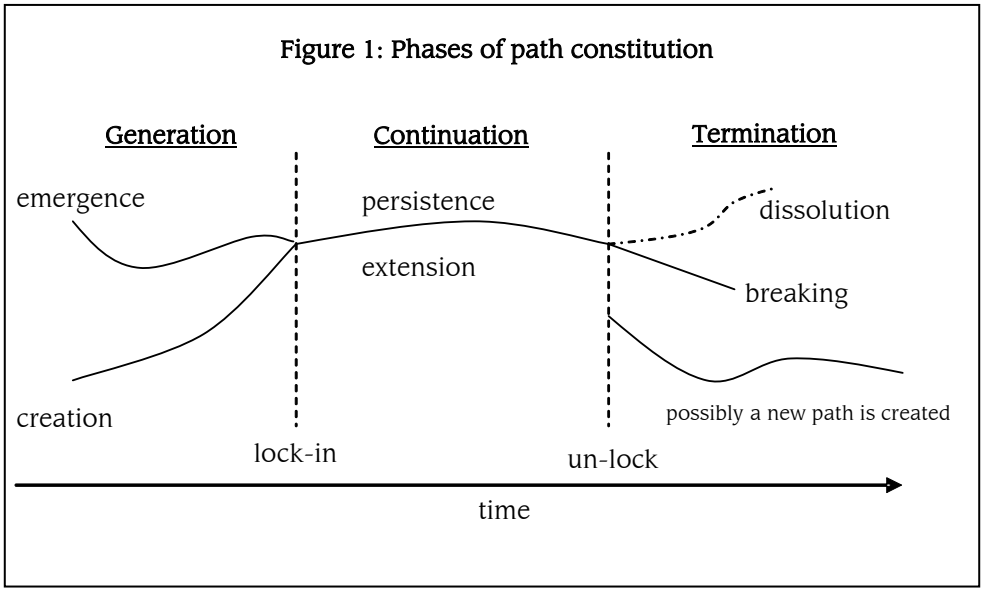

Figure 1: Phases of path constitution

Summing up the discussion above, we come to a tentative definition of a technological path: Technological paths are contingent processes characterised by an increasingly stable interlocking of socio/material elements which eventually lead to a lock-in. The stabilisation of the elements over time is a result of emergent phenomena as well as deliberate actions with respect to a specific technological option. The lock-in may be reversed by chance or by force. We see the advantage of our concept of path constitution in the possibility to integrate different empirical cases into one phase model of path processes, but also to analyse individual path processes with respect to the emerging properties and deliberate contributions of relevant and meaningful actors (see fig. 1).

In the following two chapters we seek to sociologically enrich our proposed analytical framework of path constitution. In particular we elaborate on the aspects of emergent and deliberate stabilisation of individual path processes by taking a closer look at some sociological arguments concerning the role of agency and institutions in the shaping of innovations (see also Bijker/Law 1992). In order to bridge the gap between the seemingly opposed perspectives on technological innovations either as the product of deliberate construction or as the result of emergent evolution, we revisit some arguments from path dependency and path creation under the perspective of science and technology studies and neo-institutional theory. This will further our understanding of path constitution from generation to continuation and termination, and lead to a deeper appreciation of the social dynamics at work in the constitution of technological paths.

3 Technological paths and the studies of science and technology

3.1 Studies of scientific knowledge

The studies of scientific knowledge can provide useful insights for studying technological paths, since they have significantly influenced technological development models. Examples are the notion of "technological paradigms" (Dosi 1982) or the concept of the "social construction of technology" (Pinch/Bijker 1987) which we will turn to later. In addition, thoughts from STS have significantly influenced Ga-

rud and Karnøe's notion of path creation, especially with respect to "entrepreneurs as embedded agents" and "momentum" (2001: 9-11). In this part of the paper we will sketch the fruitful contributions of this line of research for a general understanding of technological paths.

In the study of scientific knowledge, the seminal case study of the "genesis and development of a scientific fact" by Ludwig Fleck (1980 [1935]) lends valuable insights into the stabilisation and persistence of cognitive belief systems through deliberate actions. Fleck argued that a closed belief system will often persist in the face of contradictory statements. In this sense, he is often referred to as one of the first constructivist scholars opposing naïve positivist beliefs in natural science (see von Glasersfeld 1989). Fleck is interested in how a scientific belief system becomes stabilised (Fleck uses the term "Beharrungstendenz" – tendency towards persistence – to describe the stability belief systems, 1980 [1935]: 40-53). Here, Fleck specifically analyses how contradictory statements are excluded from the stabilising theory: in the early days of a theory, contradictions may be either unthinkable or may be overlooked. Later, such contradictions are actively kept secret or integrated into the established theory at considerable costs. Lastly, the most active degree of persistence can be seen when scientists resort to rhetoric and fiction rather than facts in order to maintain theoretical integrity. Fleck refers to the broadly accepted interpretations of the world (i.e. scientific theories) as "Denkstil" (i.e. styles of thinking, ibid: 165-190), which shape the individual perceptions of the world. A group of people adhering to a specific style of thinking are called a "Denkkollektiv" (meaning: collective of thought, ibid.: 53-70), who actively promote their favoured scientific theory.

The main point of the argument is that this cognitive persistence is mindfully created by actors with vested interests and – this point being important for path extension – actively defended against contradictory information. If we relate this to technology, Dosi has shown in his study on technological paradigms (1982), that the ideas of rigidity in scientific styles of thinking (Fleck 1980 [1935]), or paradigms (Kuhn 1973 [1962]), can be integrated into an evolutionary concept of technological innovation in the economy (cf. also "technological regime" Nelson/Winter 1982: 258-259). According to Dosi, a technological paradigm shapes the development of technologies because it "embodies strong prescriptions on the *directions* of technical change to pursue and those to neglect" (ibid.: 152). These prescriptions include concepts and criteria of technological "progress", e.g. the degree of efficiency or innovativeness. Hence, technology can only be evaluated within a paradigm. The effect of including and pursuing the plausible technical options as well as excluding and neglecting the implausible technical possibilities is based on the assumption that "'economic forces' … together with institutional and social factors, operate as a *selection device*" (ibid.: 152). Therefore, in its initial stages, a technology is adopted mainly because the possible alternatives do not seem feasible to the engineers who are, as Dosi puts it, "'blind' with respect to other technological possibilities" (ibid.: 153).

Nevertheless, there is a crucial difference between Fleck's social constructivist account of development and Dosi's concept of evolutionary emergence: Dosi sees the socio-techno-economic relations explaining technological developments in terms of a (mainly) *given* selection environment, whereas in Fleck's perspective the selection environment is *constructed and maintained* by the scientists. Especially Fleck's work leads us to an activity centred understanding of stabilising knowledge which can also be applied –

as Dosi demonstrated – to the development of technology. First of all, paradigms or styles of thinking – be they scientific or technological – do not emerge out of the blue, but have a history of deliberate contributions through collectives of actors. Each technological path must thus always be related to its context at any given time.

By looking at the stabilising social, technical, and economic forces in later path developments, the notions of "Denkstil" and "technological paradigm" take us one step further than the idea of mindful deviation in path creation. "Denkstil" draws our attention to the fact that a broadly accepted interpretation of a technology and of technological progress can be actively created and subsequently serves as a central factor in the stabilisation of a path. Dosi's argument about "technological paradigm" stresses the fact that criteria for technological progress are not part of a technology itself, but are part of a technological (cognitive) paradigm which can not only stabilise an existing path but also render alternative solutions unthinkable.

3.2 Social construction of technology

We now take a closer look at STS concepts which help to elaborate on the concept of lock-in and how path processes are actively supported and embedded. David associates three features that lead to lock-in in the case of QWERTY: *technical interrelatedness*, *economies of scale* and *quasi-irreversibility of investments* (1985: 334). However, these features do not stress the role of agency for locking-in a path. In the studies of the social construction of technological systems, the stabilisation and subsequent irreversibility of technological developments is considered to have numerous constitutive elements emphasising the role of agency. In the following we will look at how the notions of technical interrelatedness and quasi-irreversibility (of investments) can be enriched trough STS ideas about agency.

Hughes, for instance, uses the notion of *momentum*[8] to indicate the role of deliberate agency in the stabilisation of large technological systems: "The large mass of a technological system arises especially from the organisations and people committed by various interests to the system. … Concepts related to momentum include vested interests, fixed assets, and sunk costs" (1987: 76f.). Hughes adopts the meaning of momentum quite literally from physics as a "mass in motion" which technical systems acquire by having a *mass* (people, organisations, and technology), a *velocity* (growth rate), and a *direction* (commitments and interests). He then elaborates his understanding of momentum with regard to technological developments: "Momentum does not contradict the doctrine of social construction of technology, and it does not support the erroneous belief in technological determinism. The metaphor encompasses both structural and contingent events" (ibid.: 80). Hughes specifically highlights the role of material artefacts for the stabilisation of sociotechnical relations in time: "Durable physical artefacts project into the future the socially constructed characteristics acquired in the past when they were designed" (ibid.: 77). This can be seen as a temporally extended version of David's technical interrelatedness since it connects the "hardware" of material artefacts to the "software" of social processes over time.[9] In the QWERTY case, the material layout of the keyboard interrelates with the typist's memory of the layout and the technique of touch typing.

[8] The active generation of momentum is also central in the concept of path creation (Garud/Karnøe 2001: 17-18).

[9] Of course, one of David's main concerns was to bring time back into the picture of economics in his concept of "historical economics" (David 1993, 2001), however, Hughes points out rightly that the temporal aspects also concern the future.

Hughes brings agency into this process by stressing that the initial characteristics of the material makeup of a technology are socially constructed in the first place and even though technological systems might acquire so much momentum as to appear autonomous, i.e. beyond the control of actors, there is always room for intervention (ibid.: 79).

Because the material qualities of technology are key elements of technical interrelatedness, one has to allow for peculiarities of technologies in order to differentiate between the consequences of, say, keyboard layouts and thermonuclear reactors in the constitution of a path. Especially the stabilising forces of technical interrelatedness (David – in relation to single actors) and technological paradigms (Dosi – referring to collectives of actors) have to be acknowledged as fundamental processes of technological paths.

Let us consider quasi-irreversibility next. In David's understanding, quasi-irreversibilities relate to investments and to the asymmetry of relatively low costs needed to stay on the technological path (e.g. of using QWERTY) compared to relatively high costs of switching (e.g. to the Dvorak Simplified Keyboard, see Parkinson 1972). The afore mentioned "social construction of technology" (SCOT, Pinch/Bijker 1987) approach is primarily concerned with the social shaping of technologies *before* they become standards or quasi-standards. In this perspective, the quasi-irreversibility of technological developments is not only based on investments but also on interests. Bijker introduces the concept of *technological frame* (1995: 122) which is created out of the interaction of relevant social groups with an artefact and which then "structures the interactions among the actors of a relevant social group" (ibid.: 123). Bijker stresses two points which are usually neglected in related concepts like "frames of meaning" (Collins/Pinch 1982) or "paradigms" be they scientific (Kuhn 1973 [1962]) or technological (Dosi 1982): (1) the importance of the interaction with the artefact and (2) the possibility to include all relevant social groups, not just scientists or engineers. Within a technological frame, the relevant social groups – experts and lay persons alike – are engaged in a mutual process of defining what the matter of fact is.[10] For our understanding of the constitution of technological paths, this points to the importance of the strategic and deliberate activities of collectives of actors in creating the frame of reference in which the path is to develop. But at the same time, this highlights the heterogeneity and diversity of the relevant social groups.

The establishment of this frame is, of course, undertaken by highly motivated relevant collectives of actors with conflicting vested interests. In this phase of technological development, the technical interrelatedness must be produced by first making the interaction of the relevant social groups more stable and, in this sense, more irreversible. Bijker shows this vividly in his example of the late 19th century controversy over the shape of the common bicycle (1995: 19-100). The technological path (i.e. the dominant shape of the bicycle) and the technological frame (i.e. the dominant meaning of the bicycle) are co-constructed by the actors at the same time, and to understand path processes more generally, we think it is indispensable to include *frames* as a constitutive element of the path.

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[10] In this respect Bijker comes quite close to Goffman's concept of a "primary frame" (Goffman 1980 [1974]: 31-51), when he states that: "A technological frame comprises all elements that influence the interactions within relevant social groups and lead to the attribution of meaning to technical artefacts – and thus constituting technology" (1995: 123). In his concept of "frame analysis" Goffman was mainly concerned with the attribution of meaning in social situation, in which the primary frame provides the basic orientation for the interaction.

Furthermore, the constitution of a technological path has two sides when it comes to the concrete development of technologies by relevant mindful actors. In his classic study of the bicycle, Bijker describes the acceptance of the standard bike as the twofold process of *stabilisation* as an intragroup development (within a group actors supporting one technology) and *closure* as a process located at an intergroup level (i.e. between competing groups of actors, 1995: 84-88). For path constitution we must keep in mind that in order to stabilise a path, the relevant social groups must strive for closure by convincing and committing relevant others to their perspective. Conceptualising stabilisation as a collective process, Bijker argues that "technical change cannot be the result of a momentous act of the heroic inventor" (ibid.: 86). Bijker's understanding broadens the conceptual basis for path creation beyond mere mindful deviation. While mindful deviation might be the first step, the creation of the technological path requires stabilisation and closure on a collective level.[11]

Bijker, like Hughes, seeks to combine emergent and deliberate aspects into his study of sociotechnical change by referring to closure and stabilisation: "The irreversibility aspect of closure may seem to induce a static element in the description of technical change. This is not necessary, however, because we have the stabilization process to highlight the continuous character of technical change" (ibid.: 87). Once, in Bijker's terms, closure has been achieved, technological alternatives become relatively undisputed technological standards. These standards have the property of being *taken for granted* and hence become *institutionalised* solutions, two aspects upon which we will elaborate using new institutional theory after a short intermediate summary.

3.3 Intermediate summary

Not surprisingly, the actor model in STS is more complex than the one in path dependency. Actors are not thought of as isolated profit-maximising entities, but as groups of actors embedded in social worlds and endowed with meaning and interests that go beyond mere cost/effect reasoning. From the STS perspective, technological paths do not emerge behind the backs of actors through individual choices but are actively generated by stabilisation and closure through relevant social groups. In this process, the artefacts and human actors are mutually reconfigured until the reciprocal alignment of all entities creates a form of persistence which may exhibit forms of inertia and self stabilisation on technical, social and economic levels, but without ever locking-in completely (compare the notions of "scientific bandwagon" from Fujimura 1988; the "juggernaut" from Giddens 1990: 139; and "techno-economic networks" from Callon 1991).

We think that the notions of technological path and momentum used by Garud and Karnøe are helpful in this respect since the authors point out that: "The steady accumulation of inputs to a technological path generates a momentum that enables and constrains the activities of distributed actors" (2003: 277). If we relate the potential for deliberate activities to the phases of technological development, it seems that the further the technology progresses the possible and plausible activities for the actors become more limited. However, this could enable a new cycle of activities which can

[11] This processual perspective is used in Garud and Karnøe's notion of "embedding" (2001; 2003), but for understanding the general constitution of technological paths, we think that the more concrete ideas of stabilisation and closure better serve the purpose of finding conceptual clarity. Whereas stabilisation is specifically needed in the mode of path creation, closure must be achieved for a path to persist and, in addition, it must be constantly maintained for a path to be extended.

be seen as mindful deviations because they differ (radically) from the now taken for granted solutions. Agency can be incorporated in a general understanding of path processes in the way that actors have some sort of leeway which shapes and is being shaped by the activities of the actors: Relevant groups of actors engage in constructing the technological frames by striving for the stabilisation and closure of their preferred option. The more a technological frame is turned into a technological paradigm, the less control the actors have over it. However, a fixed set of rules and norms is the prerequisite for every mindful deviation and deliberate continuation, which is the reason why the progress of a technological path should not be equated with a simple reduction of contingency.

4 Technological paths and institutionalisation

New institutional theory can provide further insights into the socio-economic stabilisation of a technological path. Traditionally focussing on the stabilisation and homogenisation of organisational structures[12] (see Meyer/Rowan 1977; DiMaggio/Powell 1983), in the last few years, the focus of the theoretical debate has shifted towards organisational and institutional change (see Hoffman 1999; Munir 2005). We will argue that as a consequence, especially the more recent and more agency-oriented neo-institutional concepts allow for the analysis of both, the continuation and institutionalisation of technological paths, and the generation of new as well as the change of existing paths. This perspective shifts the focus towards the crucial role organisations play in the process of technological path development. In the following sections we focus on how concepts from this line of research can be used to describe the development of technological paths and their dependency on institutions, and the institutional structure of the environment in which they develop.

4.1 Path constitution as processes of institutionalisation

Social phenomena such as norms, institutions, professions, organisational behaviour, etc. are central for the understanding of technological paths and their development. Institutional theory is one possible starting point for the development of a more general concept. In the following sections the basic elements necessary for such a concept are outlined.

The notion of *organisational fields* shifts the focus of analysis on the macro level (DiMaggio/Powell 1983; Hoffman 1999). It stresses the importance of the interaction between different groups of organisations forming around a certain product, technology or issue. The properties of such a field of interacting organisations are central for the stabilisation of technological paths as well as for possible change. In addition, *institutional entrepreneurs*, especially collective ones, are a crucial driving force for institutional and technological change (DiMaggio 1988). Different *mechanisms of institutional isomorphic change* (DiMaggio/Powell 1983) lead towards the homogenisation of organisational fields. They are responsible for the stabilisation of organisational forms, and can be a central reason for the lock-in of a certain technology.

4.2 Organisational fields

A fundamental question for analysing technological paths is which level – for example individual actions, the whole world or something in between – is most influential and relevant for their development. Path processes can be described on different levels and often

[12] Even if Meyer and Rowan mentioned that "powerful organizations attempt to build their goals and procedures directly into society as institutional rules" (1977: 49), change and the active role of powerful actors is not their primary concern.

show very different properties on different levels (cf. Bassanini/Dosi 2001). The path dependency concept focuses on individual actors in the market and empirical studies on path creation focus on different levels, varying with the described empirical case. In the case of the post-it note, Garud and Karnøe focus on individual actors within one organisation (2001), in the case of the wind turbine they choose a macro perspective to compare technological development in different countries (2003).

At least for complex technologies, the relevant level of analysis is above the level of individual actors. Considering the resources necessary to develop a new technology and to exploit it, only very powerful actors are able to do so. In our time, these actors are primarily considered to be organisations or even a plurality of organisations. Consequently, to describe these processes, it is useful to focus on the organisational field as the main level of analysis. We argue for this focus as a starting point of analysis because it takes the multiple interactions of collective actors into account. This does not mean, however, that we disregard the importance of other levels like personal interaction or societal dynamics.

An organisational field is constituted by:

"those organizations that, in the aggregate, constitute a recognized area of institutional life: key suppliers, resource and product consumers, regulatory agencies, and other organizations that produce similar services or products" (DiMaggio/ Powell 1983: 143).

By so defining an organisational field, this concept focuses on a different group of organisations than related concepts like *industries* do. An organisational field not only includes organisations that produce a certain product, but also other organisations whose activities are oriented toward the activities the field is centred around. Hoffman emphasised this property of organisational fields by pointing out that it is not a certain product which constitutes an organisational field, but rather a specific issue:

"The notion that an organizational field forms around a central issue [...] rather than a central technology or market introduces the idea that fields become centers for debates in which competing interests negotiate over issue interpretation. As a result, competing institutions may lie within individual populations (or classes of constituencies) that inhabit a field, becoming situated institutions" (Hoffman 1999: 351).

Of course a specific technology or some features of it can be an issue around which a field forms, but the field is not reduced to the organisations actively involved in the production of this technology, it includes all organisations that focus their activities on this specific technology. Because of this, it allows more aspects of both to be taken into consideration, change and stability, than other related concepts would allow:

"the interorganizational field context is the appropriate level of analysis for understanding the interplay between a field's structural evolution and change in its institutional practices. By incorporating network, cultural, and historical elements, interorganizational fields provide a fruitful context for tracing and interpreting the nature and process of change in institutional practises." (Scott 1992: 333).

Organisational fields show some of the features which are central for the analysis of technological paths. They are dynamic, change over time and their structure depends on the history of the field, and cultural elements of its environment. An organisational field is more than a mere accumulation of organisations which show interest in a specific issue. Organisations within a field form groups which are – in relation to the issue of the field – homogenous within and heterogeneous among each other. In some highly structured fields, organisations belonging to one group create *meta-organisations* (Ahrne/Brunsson 2005), e.g. associations which are supposed to represent their interest within the field and allow them to speak with one

voice. Because different groups of actors have different interests in the field's focal issue, contradicting values and norms supported by different groups of organisation can exist within one field. In this case, different groups of organisations try to stabilise their perspectives, values, and norms throughout the whole field while trying to suppress alternative perspectives from other groups of organisations. This corresponds well with the concept of "relevant social groups" which struggle for the definition of a certain technology as it is used in SCOT (Bijker 1995: 45-50, 93-96). If norms and values are stabilised throughout the whole organisational field, this can provide it with an enormous amount of stability and inertia. In addition, changes in the members of the field can increase or decrease its stability.

In addition to the involved *actor constellation,* the central elements of an organisational field are the *technologies* used in it, the *regulations* relevant for the actors, and the *practices* of the actors within the field (Leblebici et al. 1991). The field's structure and dynamic are a result of the interaction of these four elements. If and how a technological path can develop depends on the structure and dynamic of an organisational field which is formed around the potential path. A certain degree of homogenisation of an organisational field is a prerequisite for path continuation. The more stabilised an organisational field is, the more it determines the way in which technology is developed within it, and the more it supports ideas generally taken for granted about technological progress shared within the field and forming the core of technological paradigms. However, the more concepts of technological progress differ within an organisational field, the more a developing path needs to be actively supported and extended. If this does not occur, there is a high probability it will be terminated or dissolve.

4.3 Institutional Entrepreneurship

It is important not to describe organisations as just passively adapting to environmental requirements. As powerful actors, organisations try to influence their environment and its development and seek to change or even create the institutional setting they require in ways which support their goals. Consistent with this perspective is the concept of *institutional entrepreneurs* (DiMaggio 1988), who actively influence institutions and institutionalisation. A good example of institutional entrepreneurship is the active creation of a technological path as described by Garud/Karnøe in the case of the post-it note. Silver succeeded in mobilising very different kinds of resources in order to stabilise the development he had started by mindfully deviating from existing rules and norms. That is exactly what institutional entrepreneurship is about. But institutional entrepreneurs are not isolated actors. While trying to influence their social environment, institutional entrepreneurs are nevertheless embedded in it. They are, for example, integrated in relevant social groups. In general, actors are influenced by their social environment. It influences their norms and values, they have to react to it, and have to take it into consideration when trying to change parts of the institutional setting (Garud et al. 2002).

Users of a technology need to be able to judge competing designs and to do so, they require accepted standards by which they can compare one technology with another. Imagine a situation in which every company sells individual systems no-one else offers. This would lead to a severe confusion of potential customers. To make a comparison possible, even competing companies may cooperate with each other in order to agree on common standards and criteria of progress as is the case in the current debate over the Blue-Ray Disc vs. HD-DVD. By developing a technology, the relevant actors at the same time mindfully construct

the technological, social and economic settings in which the path is to be generated and later continued. Institutional entrepreneurs at work in path creation are then concerned with setting up a technological frame within the appropriate technological paradigm, mobilising the relevant social groups, and influencing regulations. In short, they are generating momentum on many different levels. Even when the path has become more or less locked-in they will still have to manoeuvre skilfully within the organisational field so as to maintain and sustain the technological path, defend it against opposition, and handle the technical, social and economic fluctuations in the field.

Therefore, within an organisational field, powerful actors – single organisations or groups of organisations – influence their own institutional environment in the interaction with other groups of organisations. *Institutional entrepreneurship* within an *organisational field* constitutes the central element of institutional change.

4.4 Institutional isomorphic change

Other institutional concepts put a stronger emphasis on the stabilising effects institutions and processes of institutionalisation have. Maybe the most prominent concepts are the *mechanisms of institutional isomorphic change* (DiMaggio/Powell 1983: 67). They are described as the primary reason for homogeneous organisational structures within an organisational field. The three mechanisms are (1) coercive isomorphism, actors (especially political ones) influence or force organisations to adopt certain structural elements, (2) mimetic isomorphism, organisations copy structures of other organisations, and (3) normative isomorphism, resulting especially from professionalisation. These processes do not only apply to organisational forms in general but also to concepts of technological progress and how, for example, R&D is done within organisations and throughout an organisational field. Many of the mechanisms described in the path concepts and in the extensions through STS can be combined with these mechanisms. An example of potential consequences of coercive isomorphistic pressure is the description of the different roles of engineers in both cases of the wind turbine development in the USA and Denmark (Garud/Karnøe 2003). Isomorphistic pressure in general has the tendency to support and strengthen already prevalent institutions. Also, together with technological artefacts, it stabilises already established technologies and those which are assumed or expected to be successful.

In addition institutions within an organisational field can stabilise on a cognitive, normative and/or regulative dimension (Scott 1995b). Institutions which are stabilised on the regulative dimension are consciously set and legally enforced, cognitively stabilised ones are unconscious and taken for granted (Scott 1995a: 51). The normative dimension lies between the two extremes. In a final step, we will use these three dimensions to clarify our discussion of path constitution and science and technology studies with respect to institutional theory.

First, the *cognitive* dimension is relevant for all three approaches. In classic path dependency, for instance, it is the typist's memory which is irreversibly interrelated with the keyboard layout, and in path creation, the mindful deviation from existing procedures is stressed. Especially for the studies of scientific knowledge, the cognitive dimension plays a major role. Here the notion of paradigm corresponds well with the taken for grantedness of social institutions. However, as Fleck has pointed out, such taken for granted styles of thinking may have been actively created beforehand. For analysing path constitution we would thus have to consider the stabilising forces of taken for granted institutions or paradigms as well as influences from

mindful deviation and strategic creation of novel or perhaps just different cognitive compositions. Empirically we could then trace distinct changes in paradigms (i.e. the implementation of components previously considered utterly impossible) and analyse their role for the constitution of the technological path.

Second, on the *normative* dimension, classic path dependency reasoning has little to offer as an explanation. In path creation, mindful deviation is the deliberate aberrance from existing norms. STS always acknowledges the mutual construction of technology and social norms, especially in the form of practices. However, there is rarely any conceptual room for a normative dimension. If we think of technological paths as innovations that are largely being conducted by multiple collectives of actors, this dimension probably deserves more attention since it can be used to bridge the gap between the conscious use of legal regulations and the taken for granted paradigms. By analysing the negotiations and controversies within an organisational field, we can trace the influence of established norms for the constitution of the path while, at the same time, we remain aware of how the norms themselves might be changed in the process.

Third, the *regulative* dimension is important if we consider technological innovations to be developed by organisations within a larger regulative framework, especially if the shape of the technologies themselves is subject to laws and regulations. David (2001: 26) referred to such external shocks as one plausible reason to break a locked-in path. When looking at innovations before they become locked-in, the regulative dimension is not only important for the shape of the technology itself, but also for the specific ways of coordinated research and development between different organisations. Here we can frame the innovative manoeuvrings as forms of institutional entrepreneurship, where powerful actors seek to influence the regulative dimension in order to create a suitable context for the technological path. This has also been an issue in the STS cases on large technological systems, but again we argue for a higher analytical status. When analysing the constitution of a technological path, changes in written regulations like laws can be scrutinised in order to understand the degree in which the relevant social groups are able to consciously influence regulative frameworks in their favour and in how far this influence can be used to further stabilise the path or, as the case may be, unintended consequences arise out of those purposeful actions which again need to be dealt with.

5 Conclusion

We have argued for a conceptualisation of technological paths which takes into account deliberate actions as well as emergent evolution in path processes. Technological paths are not mere historical coincidences as classic path dependency would argue, but are influenced by mindful actors without being under their complete control. The first of our two analytical dimensions – the mode of path constitution – helps to bridge the gap between the classic evolutionary concept of path dependency and the actor-oriented notion of path creation (a similar approach has been made with respect to evolutionary economics and the concept of niches by Schot/Geels, forthcoming). The second dimension – the phases of path generation, continuation and termination – helps to sort the empirical cases with respect to the contexts the technological path is embedded in, since research and development are usually conducted under different premises than market transactions. By choosing the idea of lock-in (and then un-lock) to separate the individual phases, we highlight the different phases of path constitution as

an analytical distinction. However, this is only aimed at providing a rough grid for mapping a gradual perspective of deliberate and emergent aspects in the constitution of technological paths.

By adding these perspectives we lose some of the elegance of the original concept of path dependency. However, we think this is necessary to extend the idea of path processes beyond the initial area of application, and to overcome the simplifications from predominantly "blind" evolutionary selection processes behind the backs of actors. Drawing on the literature from science and technology studies and institutional theory, especially with respect to the role of agency and institutions in the shaping of technological innovation, we hope to further our understanding of the general constitution of path processes. The agency of collectives of mindful actors is of major significance for explaining the social shaping of technological innovations. Likewise, institutional theory brings forward the notion of the institutional entrepreneur who influences the change of social institutions thus bringing the mutual shaping of technology and institutions into focus: The analysis of a technological path, on the one hand, consists of tracing the innovative activities concerning the technological development and, on the other hand, relates them to the simultaneous fabrication of cognitive, legal, and normative dimensions of institutions. However, innovations and institutions are not like soft putty in the hands of technological or institutional entrepreneurs. Social institutions, styles of thinking, and technological paradigms make some technological developments more plausible and therefore more probable than others, they lay out conceivable trajectories and are themselves stabilised when a technology progresses along this trajectory.

Furthermore we would like to point out three insights from our discussion of science and technology studies as well as institutional theory. *First*, Bijker's analytic distinction between stabilisation on an intragroup level and closure on an intergroup level nicely points out that we are dealing with innovation as a multi-level phenomenon. Particularly on the intergroup level of closure, institutional concepts like the organisational field provide a useful perspective for analysing the constitution of a path through heterogeneous constellations of actors with diverse interests. *Second*, especially Fleck's study on the generation of a thinking style and thinking collective provides a fruitful case of how institutional entrepreneurs strategically develop a technology while at the same time creating the institutional frame for it. In this respect, the concepts of technological frames and paradigms also help to highlight the importance of non-technical aspects for the development of technologies. *Third*, the level of analysis of each empirical case needs to be specified. We have argued for organisational fields as a good starting point but, in general, a multi-level approach helps to distinguish between the unit of analysis, i.e. the technological path and its constitutive elements, i.e. the respective actions and embedding social institutions. Even the notion of an emergent suboptimal lock-in in classic path dependency reasoning can not be understood without reference to the actions of the individuals or the established market practices. Therefore, paths never exist in a vacuum but only in the rich habitat of social actions and institutions. In addition, when we look at more complex technologies today, we observe numerous technological fields interrelated in mutual stabilising processes, e.g. when we consider the interrelation of the automobile industry with the petrochemical industry, where the expertise of the engineers constructing petrol powered engines nicely interlocks with the economic interests of large oil companies.

So, what is it that distinguishes a technological path from any other

form of temporal stabilising process? In sum, we consider technological paths to be contingent development processes that extend over longer periods of time and in which specific social and material interrelations occur. On the one hand, these socio/material arrangements may emerge, persist, and dissolve while on the other hand they might be created, extended, and broken. Therefore, technological paths are *first* – and unlike path dependency or path creation – not characterised through one specific pattern of development but are constituted through the mutual configurations of social and material elements. *Second*, technological paths will display distinct patterns of development over time which can be analysed with respect to the degrees of emergent evolution and deliberate creation. It would be futile to describe the development of a technological path without emphasising the role of self-reinforcing or at least self-stabilising features.

Our understanding of path constitution allows us to look beyond mere economic increasing-returns and to integrate cognitive and institutional aspects of self-reinforcing dynamics into the picture. The ensuing stabilisation of a technological option can take the form of establishing one dominant design among competing options or the successive re-configuration of one option until it becomes a sort of standard. Eventually, this development pattern will culminate in a form of lock-in, i.e. a stable, quite irreversible arrangement of material and social components. How this irreversibility is constituted in specific empirical cases is one of the most fruitful questions to be answered in the study of technological paths.

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