Chapter 2
Institutions and Systems: Analysing Technical Innovation Processes from an Institutional Perspective

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2.1 Introduction

Institutionalism in its different facets has a long tradition in the analysis of social phenomena including the evolution and development of technical innovations. Institutional arrangements are regarded as coordinating and shaping collective action and, consequently, also influencing innovation policy. Although innovation policy addresses various kinds of innovation, this chapter will concentrate on technical innovations, product and process innovations. The studies to be reviewed examine the invention, acquisition, application, development and diffusion of new technology. They reject technological determinism, which prevailed in technology studies for a long time, and, in most cases, treat technical innovation as the dependent variable.

Innovation researchers have analysed technical innovations from various theoretical perspectives. We confine this article to studies which look at technical innovations from an institutional angle and examine what they contribute to the overall understanding of technical innovations and their repercussions. These approaches are not compared with other theories. Instead, the main focus lies on the spectrum of institutional analyses of technical innovations, including studies which primarily focus on other variables, such as economic performance, and consider the capacity to innovate only because technical innovations often enhance economic performance. These studies' suggestions or hypotheses concerning technical innovations are not less important than those developed in specialised innovation research. Thus, the studies that are of importance in our context differ gradually rather than in principle. Their conceptual understanding of institutions

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and their categorization of technical innovations may differ, but all are interested in the institutional conditions under which innovations may evolve, prevail or fail.

Three groups of studies will be included: socio-economic institutionalism examining national innovation systems as its core area; politico-economic institutionalism with recent innovation-oriented research on varieties of capitalism; and techno-sociological institutionalism embracing sociological innovation research in the field of technology. The studies are institutional in the sense that they draw on particular institutions or institutional constellations as societal meso- or macro-phenomena to explain technical innovations. In their majority, they explore the effects of institutions on technology and only rarely do they touch upon processes of institutional development or change triggered by technical innovations if and when, for example, the complexity of an innovation "necessitates" a regulatory response (Feick and Werle 2010, pp. 45–47). Thus, after years of technological determinism we are now confronted with the danger that the pendulum will swing in the opposite direction towards some kind of institutional determinism. To escape the potential determinist trap, technological and institutional changes must be related to each other and their interdependence must be examined. Appropriate approaches can be found in several of these socio-economic, politico-economic and techno-sociological analyses to be discussed now.

2.2 Socio-economic Institutionalism

Since the 1980s, socio-economic research has been increasingly concerned with technical innovations. In contrast to neoclassical approaches, which treat technical innovations as exogenous variables, these studies try to endogenise innovations and to discover conducive or hindering factors. These are not necessarily always or in the first place market-related factors. Rather, the multifold institutional structures of capitalist nation states specifically determine both form and speed of technological progress (Dosi 1988, p. 1148). After several country comparisons displayed striking differences and changes in relative economic performance, the attention of researchers shifted to national institutions and their significance for the countries' innovative capabilities – thereby assuming with reference to Schumpeter that technical innovations enhance economic performance and growth.

2.2.1 National Innovation Systems

Among the socio-economic innovation studies with an institutional orientation, those focusing on national innovation systems (NIS) particularly stand out. Following Porter's (1990) groundbreaking investigation into the (particularly technological) competitiveness of ten leading industrialised countries, these studies show that varying national institutional constellations account for the divergent innovative

capabilities (Edquist 1997). At the centre of these analyses lie product and process innovations within technology-based industries (Carlsson et al. 2002). Inventions and, more importantly, the development and diffusion of innovations are not considered as single acts, but instead as processes which are formed by institutional constellations and structures that vary among nations.

Prominent early studies of NIS, such as those by Freeman and Nelson, show that the prevailing understanding of institutions is rather vague and extensive, and that the concept of institutional systems remains unclear (Freeman 1987; Nelson 1988). Freeman describes NIS as "the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies" (Freeman 1987, p. 1). In his study of Japan, he alludes to the industrial structure, the education and training system, the research and development activities of businesses, and the long-term strategies of the MITI (Ministry of International Trade and Industry). Institutions encompass not only legal rules but also organizations and their activities and strategies. Such a broad understanding of institutions and the vague system concept are also typical of subsequent studies. In a more recent anthology, Nelson and colleagues define NIS as "the cluster of institutions, policies, and practices that determine an industry's or nation's capacity to generate and apply innovations" (Steil et al. 2002).

At an early stage and in collaboration with Perez, Freeman also developed a classification for innovations. Their distinction between *incremental* and *radical innovations* is used particularly frequently. Incremental innovations are seen as relatively continuous improvements of technology within one line of development. Radical innovations occur discontinuously, often as results of strategic research and development activities, and lie outside given technological trajectories (Freeman and Perez 1988, pp. 45–47).

Both Nelson and Freeman regard institutions as relatively resistant to changes. Hence, for the success of technical innovations it is decisive that they fit well into the institutional structures and that these structures have a strong absorptive capacity. Ultimately, the development and/or quick diffusion of innovations requires compatibility ("match") of new technologies and institutional constellations. As institutions have a relatively low adaptability they are treated as part of the selective external environment which ultimately determines the destiny of innovations.[1] These emerging contours of an evolutionary theory of technical innovations are elaborated on more fully by Nelson (Nelson and Winter 1982; Nelson 1987). According to Nelson, the capitalist profit motive, the competition among different sources of innovation and the market selection constitute the crucial elements of the process of technological evolution. The "selective environment" takes effect via market demand and thus determines the success or failure of innovations.

[1] Freeman shows that Japan's institutional constellation was conducive to process innovations and lead to competitive advantages in the consumer goods industry, in the automobile production and in the production of semiconductors. In other areas of technology, Japan lacked innovativeness because its institutional system was less supportive to innovations.

Corresponding to Nelson's extensive understanding of institutions, this environment also comprises numerous organizations: firms, industrial research laboratories, research universities, vocational training centres, as well as government agencies with their technology and industrial policy. These organizations, their strategies and relationships vary across countries (Nelson and Rosenberg 1993). This also applies to institutions in a narrower sense, such as the, in Nelson's view, crucial rules for appropriating and securing the profit of innovations. In the relatively simple evolutionist scheme of variation and selection, individual and corporate actors promote technological change by producing innovations (variation), while the national institutional systems in the broad sense separate the wheat from the chaff (selection).

Nelson and his colleagues conducted or inspired numerous studies in which innovative capabilities and activities are primarily measured by the expenses for research and development or by the number of patents. Another occasionally used indicator is the balance of imports and exports of high-tech industries. These indicators are differentiated according to economic sectors and whether private or public, non-military or military, as well as whether university-based or non-university research organizations are involved. Yet, no systematic country comparisons were carried out by Nelson, although he studied 15 countries in the beginning of the 1990s. Aside from the observation that strong and competent enterprises form the most important precondition for an innovative, prospering economy, no generalizable conclusions could be drawn, especially with regard to the effects of institutional constellations. But it becomes clear that a country's attempt to copy institutional factors of another, in certain areas particularly successful, country is not very promising due to the complex and multi-layered nature of innovation systems. Especially, taking cues from the U.S., complementary relationships between industry and university research on the one hand and the strongly differentiated (public) research funding on the other have been emphasised as crucial for the process of innovation (Mowery 1994, pp. 79–106; Riccaboni et al. 2003). Moreover, the availability of venture capital is the key to rapid commercialization of innovations mainly because innovative researchers are now able to leave research laboratories of universities or major enterprises and establish their own start-up companies (Mowery and Rosenberg 1993).

Lundvall developed an additional variant of the NIS-approach. According to him, the countries' historically grown economic structures, including industrial relations and their organizational and institutional structures (e.g., of research and development), are characteristic for their respective innovation systems (Edquist and Lundvall 1993). Within these frameworks, and dependent on them, innovation processes unfold as cumulative, interactive and continuous learning processes (Lundvall et al. 2002). The learning processes which ensue from the interactions among producers as well as between producers and users of technology facilitate especially the incremental development and diffusion of innovations (Lundvall 1992). This holds for technical innovations, be they process or product innovations, as much as for organizational changes of enterprises or institutional innovations. Finally, Lundvall emphasises that incremental changes resulting from learning

processes are more important for a country's economic performance than the ability to create something radically new.

Within this spectrum of proposed approaches and perspectives, a large number of studies investigate the connection between institutional constellations and technical innovations. Although the list of relevant institutional factors remains enumerative, the studies successfully show that, in general, firms – securely anchored in national institutional systems – are the central agents for innovation and benefit from this situation. As a consequence this further stabilises the national institutional systems. At the same time, this has the effect that countries continue to be strong in certain technologies and weak in others. Complementarities emerge between scientific research at universities and public research organizations, research and development within enterprises, strategic networks of cooperation, public technology and industrial policy and other factors with the result of pronounced sectoral specialization patterns (Archibugi and Pianta 1992; Guerrieri 1999).

Follow-up studies in the tradition of the NIS approach reveal stagnation of the theoretical, and to a lesser extent empirical, vitality. This also holds true for more recent studies which were concerned with the excellent performance of the U.S. economy in the 1990s (Larédo and Mustar 2001; Steil et al. 2002; Block and Keller 2009). While the concept of national innovation systems can still be considered very vague, the institutional components are now more strongly emphasised than other system elements. However, there is still no clear-cut definition of what is systemic in national innovation systems (Carlsson et al. 2002).

Given these problems, it is not surprising that more recent studies in the NIS-tradition examine the connection between specific aggregates of institutional regulations and technical innovations, rather than looking at entire institutional constellations. Their main focus is regulations for the protection of intellectual property. In the past 30 years, far-reaching changes have occurred, with the consequences being discussed in these studies. Most of them concentrate on the United States. Here, particularly, the possibilities of obtaining patent protection have been extended severely since the early 1980s (Jaffe 2000; Gallini 2002). Not only was the period of validity for patents prolonged, but also the circle of organizations eligible to file patent applications was enlarged. It now includes universities and public research organizations which are allowed to patent innovations even if they were publicly-funded. More importantly, patent protection was extended to previously not patentable fields. In this context, the granting of patent protection for living organisms (such as genetically engineered bacteria), DNA sequences or other biotechnological and genetically modified innovations is particularly remarkable. But also the right to patent certain software products, which have been protected merely by copyright or not at all in the past, has raised numerous research questions. It is especially interesting to understand the effects of improved patent protection on the increase of patent activities in several countries and to check whether intensified patenting reflects an increase of successful innovation efforts (Gallini 2002, p. 133). It has been shown that strategic patenting and licensing behaviour often generates unexpected and innovation-hindering effects (Heller and Eisenberg 1998; Hall and Ziedonis 2001). Generally, the

relationship between the legal opportunities to patent and innovative behaviour is more complex than frequently assumed (Bessen and Meurer 2008).

2.2.2 *Repercussions of Innovations on National Innovation Systems*

Most studies on the relationship between NIS and technical innovations assume that institutions change very slowly and that the diffusion of innovations depends on their compatibility with the institutions. Only in the long run and triggered by radical basis innovations are repercussions on the system of institutions expected. Freeman and Perez (1988) suggest that radical and self-accelerating innovations, which simultaneously occur in several technological fields, lead to a drastic structural shift of the entire economy. As a result, a change of the hitherto dominating techno-economic paradigm can be observed. A new "technological regime" with characteristic institutional structures is established which continues to be prevailing over centuries and only changes in long cycles. Hence, in the rare occasion of technological revolutions (and usually only then) technologically induced new institutional arrangements may evolve (Freeman and Louçã 2002).

Porter (1990) refers to possible medium-term institutional change as a reaction to technical innovations, particularly in technology-intensive industries which play a decisive role in the competition of national economies. These industries emerged under conditions originally created by the countries themselves which subsequently were influenced by the industries. Driving forces are multinational enterprises which are interested in optimally benefiting from the potential of new technologies (see Pavitt and Patel 1999). Other studies which show that institutional differences between different technologically shaped sectors within a country tend to be greater than differences between countries also point to repercussions of technology on institutional structures (Carlsson 1994; Breschi and Malerba 1997). The close examination of such sectoral innovation systems, so-called technological systems, opens better possibilities of tracing the interactions between technology and institutions, rather than only considering entire national systems (Geels 2004).

If at the same time technical innovations are analysed in more detail, it renders endogenising institutional developments possible. Institutional changes can at least partially be explained by technical innovations (see Dolata 2009). This is indicated by research on the protection of intellectual property rights in technologically innovative sectors. Graham and Mowery (2003, p. 254), for instance, characterise the relation between software innovations and legal developments towards a stronger protection of intellectual property rights in the software industry ("software patents") as "co-evolution, involving mutual causation and influence." This corresponds to rather programmatic considerations regarding the "coevolution" of technologies and institutions which Nelson (1994) coined a decade earlier.

2.2.3 Results

Summarizing the state of socio-economic analyses studying national innovation systems, it can be seen that the influence of institutional variables on technical innovations has been made plausible, but rarely has it been specified. Innovations comprising physical artefacts as well as technological know-how are not examined in detail. Specific attention is paid to input factors for innovation, such as public and private expenses for research and development. The output of innovation processes is often only measured by how often or how seldom innovations evolve. Some studies count the number of patents (e.g., Faber and Hesen 2004) even though changes in the number of patents do not necessarily correspond to the number of innovations. In general, technology itself is measured by simple undifferentiated categories. Most commonly, the distinction between radical and incremental technical innovations, as well as between product and process innovations, is used. It is emphasised as a general rule that innovations occur surprisingly and that their exact emergence cannot be fully explained. This does not contradict the fact that innovative technological developments tend to occur within a "technological paradigm" which constitutes a relatively stable path of development (Dosi 1982).

Regardless of the specific substance of technical innovations, the institutional conditions of countries and sectors can be judged according to whether they facilitate or impede innovations. Similar to the pioneering works, more recent studies also stress the developmental potential of technologies, the size of markets, the possibility to finance and acquire ownership rights of innovations, the structure of the respective sector, and investments in publicly available knowledge as most important factors which trigger and structure innovations. Potential repercussions of technical innovations on institutional structures have gained increasing attention. Newer studies suggest that national innovation systems tend to converge towards stronger market coordination, partly due to external pressure (see Henisz et al. 2005). Nonetheless, crucial components of national institutional constellations and, accordingly, national differences remain notably stable.

2.3 Politico-economic Institutionalism

One central shortcoming of studies pertaining to national innovation systems is their lack of a theoretical concept of institutions that could be related to and integrated with general institutional theory. Instead, institutions and institutional constellations are analysed in isolation without examining their potential relations. This is explicitly criticised by Hollingsworth, who argues that the problem is not a lack of institutional approaches, but rather their excessive supply. With a theory of innovation in mind, he contends that the specific components of a society's institutional structure and the relations between them should first be identified before any

statements can be made regarding their influence on a country's innovative capacity (Hollingsworth 2000, p. 596).

In his understanding, national and sectoral arrangements of institutional governance of production constitute *social systems of production* which can differ from country to country but generally show a certain degree of internal coherence with often interdependent, complementary components (Hollingsworth and Boyer 1997; Hollingsworth 2000, pp. 613–619). Together with the structure and norms of relevant organizations (especially enterprises and public research organization), a society's social production system shapes what Hollingsworth calls its "innovative style." Accordingly societies can be more or less innovative, their innovations can be incremental or radical, and they can typically be developed in emerging high-tech sectors or in mature industries. While Germany develops successful incremental innovations in sectors such as chemistry, electrical engineering, mechanical engineering or automotive engineering, the U.S. has a rather radical innovation potential. In newer industries such as electronics or biotechnology the U.S. produces – in short time periods – completely new complex products which often have a relatively short life-span (Hollingsworth 2000, pp. 626–633). The social systems of production of both countries differ with respect to the structure of enterprises, the industrial relations, the vocational training system, the financial markets, and the university-based research system. These differences are decisive for the diverging innovation styles.

2.3.1 Varieties of Capitalism and Innovation

Hollingsworth alludes to a set of variables which play an important role in more recent politico-economic research on the *varieties of capitalism* (VoC). Similar to NIS-studies, VoC-research started in the 1980s. The goal is to explain noticeable performance differences between national economies focusing not on more or less successful public economic policies, but rather on political-institutional factors, i.e., different organizational forms or different varieties of capitalism.

Similar to studies about national innovation systems, VoC-research concentrates on countries or sectors as units of analysis, but in a more systematically comparative way. Research is directed at the global competition of social production systems and the resulting institutional change of national capitalisms. Hence, the studies not only raise the question of how institutions influence a country's economic performance, but also how institutions develop and change. However, most studies are still fixated on contrasting global convergent and national path-dependent development.

From the outset, VoC-studies have aimed at creating a typology of institutional constellations in order to classify the countries or sectors which are to be compared. A classification developed by Soskice in the last decade is generally regarded to be the most elaborated. Picking up the concept of social production systems, the author suggests that production regimes shape the rules of the institutional framework, which helps the "microagents of capitalist systems" to organise and structure their

relations with each other (Soskice 1999, p. 101). Important elements of this view, which focuses on the production side of economies, include the system of corporate finance, the various models of corporate governance, the employment contract law, the industrial relations, the education and vocational training systems, and finally, the rules which govern the relations between enterprises (competition and antitrust law, technological transfer regulations, standardization guidelines, etc.). Soskice distinguishes two basic types of capitalist economies: *coordinated market economies* (CME) and *liberal market economies* (LME). In the case of CME, employers are integrated in a network of associations, coordinating wages, training and employment relations internally and together with organised labour. The network has a cooperative spirit and a long-term perspective. This includes corporate finance, which is provided in the form of long-term 'patient' capital. In the other basic type, the LME, short-term market coordinated relations prevail between enterprises, but also between enterprises and their labour force or their investors (Soskice 1994; Hall and Soskice 2001).

In the centre of attention stand enterprises and their strategies. While the enterprises can act autonomously, their actions are influenced and channelled by the afore-mentioned institutional elements. The results of such actions are hence determined by the interrelation of institutional influences and autonomous strategic interaction (Hall and Soskice 2001). They are thus never exclusively determined by preferences, resources or strategies of actors, or solely by the institutional context. This perspective is still predominantly programmatic in VoC but almost completely absent in studies on national innovation systems. Although NIS-studies regularly emphasise the importance of enterprises in the innovation process, they are merely treated as a passive "black box", influenced by "macro-social determinants" including institutions (Coriat and Weinstein 2002, p. 274).

Liberal market economy prototypes (within the OECD countries) include the United States in the first place but also the UK, Ireland, Canada and Australia. Germany is seen as the prototype of the group of countries with a coordinated market economy, to which Austria, Switzerland, Sweden, Norway, and Japan also belong. When Germany and the US are seen as two endpoints of a continuum, all other mentioned countries are very close to one of these two endpoints. Still others, including the Mediterranean countries, lie in "ambiguous positions" (Hall and Soskice 2001, p. 21). On the one hand they have a relatively liberal labour market, but on the other their governments strongly influence the economy and their agricultural sector is relatively large.

Only rarely do we find references to technical innovations in the studies about the varieties of capitalism. Generally, the studies' dependent variable is economic performance, which is shaped by the comparative institutional advantages each country has. Every institutional constellation has specific strengths and weaknesses, and no constellation is superior to others in all dimensions of economic performance. This also holds for technical innovations, which are considered in VoC-studies mainly because they influence the economic performance. Hence, innovations function as intervening variables. They are shaped by institutions and – in turn – affect performance.

Similar to the NIS-literature, the VoC-literature rather coarsely differentiates between types of technical innovations. The central distinction lies between incremental and radical innovations. It is argued that enterprises in liberal market economies exhibit a strategic alignment toward radical innovations. These innovations, mostly only patented inventions at first, emerge in the new high-tech sectors. Small start-ups especially, financed with venture capital, and – though less frequently – major enterprises introduce new products into the market or at least make the products marketable. Due to the high speed of innovation, products, which are often components of complex technological systems, have a relatively short lifespan. Under such conditions, enterprises are committed to short-term profits which they can achieve if they employ a staff with a high level of general qualifications. The enterprises must continually and flexibly position themselves vis-à-vis changing market conditions. This requires adaptable employees and involves high staff turnover. Regarding the specific institutional conditions, this is compatible with LME but not with CME. Hence, LME promote radical innovations while CME are favourable to incremental innovations (critical Streeck 2011; Soskice 1999; Hall and Soskice 2001).

In some more recent VoC-studies, the distinction between radical and incremental innovations has been developed further. This facilitates substantiating the effects of institutional constellations on technical innovations. One very interesting distinction differentiates between "discrete" and "cumulative" (or "platform") technologies, introduced in a study of enterprises in the German bio-technology and software industry (Casper et al. 1999). The authors attempt to explain why, in a coordinated market economy such as Germany, enterprises which work on radical innovations may still prosper. They attribute this to the fact that in the area of bio-technology and software one can find technologies which fit into the German institutional framework. Successful enterprises, it is argued, specialise in cumulative rather than discrete technologies. These broader platform technologies develop over a longer period of time in a comparably stable way. In information technology, it is not the standardised software, but the service segment for commercial users of software. These users ask for integrated system solutions that are regularly expanded and updated. From the perspective of technical development, this is a cumulative and long-term process. The relations of service companies to their customers are also of a long-term nature. The service providers' staff accumulates specific cumulative know-how which offers them a long-term employment perspective. Similar developments have been observed in bio-technology. German enterprises have specialised in the development and production of instruments and software which are used for pharmaceutical research or the production of pharmaceuticals. In contrast to the end products of this industry, they are applied and demanded constantly and hence must undergo continuous further development (Casper and Glimstedt 2001; Casper and Matraves 2003).[2]

[2] The view that platform technologies possess a cumulative character and can be continuously developed over years is often challenged (Dolata 2003). However, this does not alter the usefulness of distinguishing between discrete and cumulative technologies.

2.3.2 *Repercussions of Innovations on National Production Regimes*

One finding upon which all studies on varieties of capitalism agree is that national institutional constellations are resistant to rapid fundamental change despite the pressure of globalization. This is due to interdependencies and complementarities of institutions within the established national constellations (Amable 2000). Recently, this understanding of a close link among institutions has been criticised methodically and empirically (see Höpner 2005). The implication that there are not even niches in which innovations can develop, unless they match institutionally, had to be abandoned (Crouch 2003; Kitschelt and Streeck 2003; Lange 2009).

This could reinforce the discussion triggered by Kitschelt (1991) in the early 1990s emphasizing that technical innovations exert pressure to change on national institutions. Kitschelt criticises the fact that research on the performance of national economies tends to ignore the sectoral differentiation of national institutional arrangements and the structural features of technology. Whether or not a new technology can establish itself and develop further depends on corresponding sectoral structures of institutional governance. If these structures are missing they can be created to the extent that the encompassing national regime structures allow such a change. Within the framework of stable national institutions, sectoral structures are hence able to change under the influence of innovative technologies. Technical innovations may thus promote institutional change towards a national regime structure which shows a broader mix of sector-specific institutions and a wider array of national technologies. Kitschelt illustrates his considerations by comparing Japan's development to Western industrial countries. The author strives to describe in great detail the structures of technology and the corresponding institutions by using categories which are closely related to theories of institutional governance. These include Perrow's distinction between loosely and tightly coupled technological systems and between linear and interactive system processes (Perrow 1984), as well as the different types of governance in Williamson's transaction cost theory (Williamson 1985). Certain technology features such as "asset specificity" or "uncertainty about the causal structure of the technology" (Kitschelt 1991, p. 464), which are relevant for a transaction, co-vary with Perrow's characteristics of (more or less complex) technological systems. They each require adequate sectoral institutional environments.

Kitschelt's strategy is remarkable because he applies a differentiated, yet nonetheless rather formal concept of technology or technological systems. This allows systematically integrating technology into the analysis as an endogenous as well as exogenous variable in the process of constituting an industrial sector. The evolutionary variety of technology is reduced through institutional influences. However, technological systems are still too multifaceted to be regulated efficiently by a uniform national institutional structure. Therefore, technology-related sectoral governance structures are established. No country has general political-institutional preconditions which are equally beneficial to the development of adequate sectoral

institutional structures given the diversity of technological systems. Overall, however, institutional variety at the national level benefits the development of technology-adequate sectoral structures and hence technical innovations, which, on their part, stabilise or even enhance this variety.

2.3.3 Results

Most studies on the varieties of capitalism do not focus on technical innovations. Whenever they are mentioned, they appear as dependent variables which remain under the influence of specific national institutional constellations. Hence, innovations only have good implementation opportunities if they are compatible with the national system of institutions, regardless of whether they were developed externally or within their respective country. Different institutional systems promote different types of innovations. Whereas liberal market economies tend to produce radical innovations, coordinated market economies provide favourable institutional conditions for incremental innovations.

Some enterprises acting in coordinated market economies have prospered in industries characterised by radical innovations such as biotechnology or software. This surprising fact is explained by further distinguishing certain types of radical innovations. Not all radical innovations are discrete in nature. Some are cumulative or (relatively broad) platform technologies which can be developed and improved continually over a longer period of time. This is compatible with coordinated market economies. Only rarely has it been suggested that technical innovations exert pressure on institutions to change. In Germany, the development of radical innovations has increasingly attracted venture capital – virtually incompatible with the institutions of a CME – which in turn provides incentives for further radical innovations and institutional adaptation.

2.4 Techno-sociological Institutionalism

Both socio-economic and politico-economic analyses of technical innovations generally fail to provide a detailed examination of technology and its respective stages of development. Sociological technology studies differ in that they focus on technology in more detail. But sociological technology studies often neglect the institutional arrangements in which technology evolves. The traditional rules of technology studies lack explicit reference to institutions and institutional explanations (Rammert 1997). Instead, most of the studies share the "enactment perspective" which regards the emergence and development of technology as a contingent process of social appropriation exclusively at the micro-level of individual or collective action and practice (see Schulz-Schaeffer 2000).

Institutionally oriented studies have typically been concerned with the emergence and development of technological infrastructure systems or, more general, *large technological systems* (LTS). These studies understand institutions as rule systems and focus on the problems of coordination and regulation which emerge during the process of technology development.

2.4.1 Coordinating Innovations Through Hierarchies, Markets or Networks

Based on the generic types of institutional governance – *hierarchies*, *markets* and *networks* – specific institutional arrangements, actor constellations and actor strategies are analysed regarding their effects on technology.

Research on LTS was initiated by the works of technology historian Hughes (1983) who analysed the early development of electricity supply systems in Chicago, London, and Berlin. Such systems do not simply follow technical imperatives in their development nor are they exclusively shaped by inventors and system designers with an entrepreneurial spirit. Rather, the political-institutional framework is crucial as well. Following a *phase model*, the systems develop from the stages of invention and innovation, through technology transfer, growth and competition, to the consolidated state of "momentum". Although the basic technologies for electricity supply in all three cities are similar, the systems differ with regard to the degree of centralization and integration, and also to efficiency; however, no one system outperforms the others in all respects. The decisive factors for the observed differences lie in the institutional conditions which coordinate the process of development. Whereas market factors were crucial in Chicago, corporatist networks in Berlin and administrative hierarchies in London coordinated the technical development (Hughes 1983, pp. 165–261).

The history of technological infrastructures (especially telephone, railway, electricity) shows that they unfold almost always as public or private politically tolerated and regulated territorial monopolies (see Mayntz and Hughes 1988). Large organizations internalise the system development and hierarchy has been the predominant mode of coordination for a long period of time (Chandler 1977). In general, this institutional constellation is conducive to the development of "conservative" technical innovations (Hughes 1982) and it rules out internally initiated radical system changes. Thus, far-reaching changes of technological infrastructures are typically the consequence of political-institutional changes. This has been shown by Schneider (2001) in his evolutionary analysis of the institutional transformation of telecommunications in the six most important industrial countries over the course of two centuries. The mode of coordinating telecommunications has shifted from state monopolies to more market-based structures. Deregulation and liberalization triggered a vertical de-concentration and unbundling of the systems and their architecture (see Mayntz 2009).

The politically initiated institutional change towards more market coordination alludes to its superior innovation efficiency (Baumol 2002). Hierarchical and centralised architectures are transformed into decentralised, modularised and networked architectures. The internet can be considered the most impressive example of this transformation process which released the extraordinary innovative potential of this technology (Werle 2000). Aside from some coincidental decisions, the institutional preconditions in the U.S. in the 1980s and early 1990s account for the quick national and subsequent international expansion of the internet. In contrast to Europe, U.S. telecommunications were already deregulated to a substantial degree and market principles coordinated the U.S. software industry, while European governments still supported "national champions" and protected them from competition. Moreover, the U.S. higher education sector (in which internet spread at first) was also organised competitively to a certain extent. Originally, the internet was publicly funded and developed in a protected niche. But it subsequently established itself on the market without further public support (see Mowery and Simcoe 2002). At the same time, European governments which wanted to outcompete the U.S. internet promoted national research and education networks which developed in a hierarchical institutional setting controlled by the telecommunications monopolies. But these networks failed as soon as the internet was allowed to enter Europe and the national telecommunications markets were opened for internal and external competition. The internet's advantage has been that – partly due to the heterogeneous institutional context of the U.S. – its generic protocols were designed to handle technical heterogeneity and autonomy of sub-networks and to interconnect these networks successfully. Conversely, in the hierarchical context of the European countries, the efforts of the engineers were directed towards developing rather centralised technically homogeneous networks which experienced almost un-surmountable problems when these networks were to be connected to networks with different standards (David 2001; Werle 2002).

The studies on innovations in large technological systems are generally restricted to contrasting the governance forms of market and hierarchy. Analyses of network forms of coordination which especially gained attention in the 1990s focused mainly on the level of enterprises and the organization of production (Powell 1990; Hirsch-Kreinsen 2002). The possible influence of networks on the development of technology was discovered relatively late. A special type of networks, the so called "innovation networks" which promoted the evolution and diffusion of *new* technologies moved into the centre of attention. These heterogeneous networks connect "technology-generating, technology-applying and technology-regulating social systems" with each other (Kowol and Krohn 1995, p. 78). Based on negotiations and trust, they help to manage complexity and to reduce uncertainty where markets tend to fail regarding the flow of information and where hierarchies fail with respect to flexibility (see Küppers 2002).

Rarely is the relationship between the structure of innovation networks and the technical innovation process specified. Weyer et al. (1997) take a first step in this direction, analysing in four case studies the evolution and development of the European aircraft Airbus, the Personal Computer, the high speed train Transrapid,

and Satellite Television. The authors argue that successful innovations pass through the phases of emergence, stabilization and implementation as independent stages of development. From one stage to another the network of actors that are innovation-enhancing changes. In the starting phase, coincidental inventions of innovative actors are integrated into a model which includes the basic specifications of architecture, production and utilization of a technology. Potentially interested actors form a network. In the subsequent phase, strategic actors set up networks in order to promote the technology. This step absorbs uncertainty, facilitating the further development of the innovation. The innovative idea and the general model lead to a first technological prototype. In the final implementation and diffusion phase, the network opens itself to include new members such as users, affected third parties, operators, and also critics. New areas in which the innovation can be applied, as well as new patterns of utilization are invented in this phase. According to the authors, it is crucial for a successful innovation that a network is formed and socially consolidated in every single phase of development. These networks must be able to reach necessary decisions and actively participate in the construction process. Otherwise, the innovation will stagnate on the stage it has reached and not move onto further stages. For the successful implementation of a new technology in particular, a rigorous opening of the networks is essential (Weyer et al. 1997, p. 330).

Similar to this research group, other studies also restrict themselves to exclusively analyse the success or failure of innovations and of the enterprises involved in the innovation networks. The development of successful technical innovations appears to strongly depend on the formation and stabilization of networks in which actors from different institutional sectors in a certain region such as Silicon Valley work together (Castilla et al. 2000). Also, government agencies can play an important role promoting and moderating networks of innovation (Giesecke 2000). This suggests using a multilevel approach, especially if the development and transformation of large technical systems is studied (Geels 2007).

From an institutional perspective, it is important to note that innovation networks link different institutional sectors with each other. This has also been emphasised in studies which point to the close connection of institutional sectors and logics of action. Some of these studies refer to the innovation-promoting effect of symbiotic "triple helix" constellations among universities, industry and governments (Leydesdorff and Etzkowitz 1998). Others – following Gibbons and colleagues – stress the importance of these linkages and networks for the emergence of new forms of knowledge generation (Gibbons et al. 1994).

The networks' institutional character as a specific mode of coordination is nicely revealed by a study of formation, dissolution and change of networks in the field of biotechnology. Powell et al. (2005) analysed these phenomena over a period of more than 10 years in the U.S., thereby meeting the requirement to describe networks in their dynamics and to identify the underlying mechanisms (Jansen 2002). They analyse the effects of changing rules and preferences for partner selection on the population and structure of networks. These have changed remarkably over the course of time, but the networks have continued to show a high degree of heterogeneity. Taking everything together, the development of innovative

bio-technology depends on the composition and structure of the networks rather than on the fate of individual hubs or organizations (Powell et al. 2005).

It is not surprising that networks are especially widespread as modes of coordination in countries with a liberal market economy, and that they are more variegated in LME than in coordinated market economies (Owen-Smith et al. 2002). The networks, in which actors connect with partners from other institutional sectors, constitute a basis for the development and diffusion of radical innovations. In purely atomistic exchange relations, on the other hand, actors working on such innovations can hardly survive. But networks as such do not guarantee an innovation's success either. If they were superior in every respect other modes of coordination would, in functionalist terms, completely disappear (Podolny and Page 1998, p. 66). Not only markets and hierarchies, but also networks can fail.

2.4.2 Repercussions of Innovations on the Modes of Institutional Governance

The majority of sociological technology studies treat innovation as the dependent variable, while institutions are seen as constant or difficult to change. To establish itself the innovation must fit in or be compatible with the institutional environment. Hence, unsuccessful innovations are not necessarily in every respect inferior to successful innovations. They merely do not match their institutional environment as suitably as successful innovations might. However, technology is not always and exclusively a dependent variable. Large technological systems are especially expected to influence institutions and to strengthen their coordinative function (Mayntz 1993). Similarly, Krücken and Meier (2003) emphasise that network structures of institutional coordination and technical innovations are recursively connected to one another.

More recent technology studies explicitly make use of the concept of co-evolution when they analyse socio-technical transformation and transition processes (Rip and Kemp 1998; Geels 2004, 2005). The studies emphasise the crucial role of technology, particularly of radical technical innovations, in such processes, but reject technological determinism. According to the studies, radical innovations are hard to predict and difficult to shape. Often, they emerge in niches. Generally, the development of technical innovations follows its own logic, resulting in pressures on the surrounding institutional structures to change. These structures tend to be inert, but some windows of opportunity are occasionally opened through which changes can be achieved. The innovation process is an interactive, co-evolutionary multilevel process, involving technological artefacts, individual actors, organizations, sectoral institutions, and finally, socio-technical regimes (Geels 2007). Technical and social factors mutually influence each other. For the transport industry, the historical process of co-evolution in ocean shipping (from sailing ships to steamships), in air traffic (from propellers to jet aircrafts) and in road traffic

(from horse-drawn carriages to automobiles) has been traced by (Geels 2005). The author shows in a phase model, which is more heuristic than explanatory, that usually one technology became dominant for a certain period of time.

2.4.3 Results

In conclusion, sociological institutionalism understands the evolution of technical innovations as a result of coordinated efforts whereby the mode of coordination can take the institutional forms of market, network and hierarchy. These forms are often interlinked. While some studies further differentiate them, the initial typology is not advanced systematically. In some cases a correspondence can be found between the mode of coordination and the type of technical innovation. The transition to stronger market-based coordination, for instance, was accompanied by decentralization and looser coupling of telecommunication networks, facilitating the evolution and integration of radical innovations. Yet, it is still an open question how further internal differentiations of the modes of coordination affect technology.

Sociological technology studies with an institutional background are more interested in the development of large technological infrastructures than individual technical artefacts. In these studies, technology is not analysed as sophisticatedly as in other fields of the sociology of technology. But a stronger differentiation would not be useful either if the institutional concepts are not more differentiated as well. More recent research strives to overcome institutional determinism, which exclusively regards technology as a dependent variable, by interpreting the technological and institutional development as an interrelated co-evolutionary process. In such a process, the dynamics of technical innovations can exert pressure toward institutional and social changes.

2.5 Perspectives: Co-evolution and Interaction of Technology and Institution

In the institutional approaches reviewed here and summarised in the Table 2.1, technical innovations are of varying importance. Socio-economic analyses are interested in general innovative capabilities, referring to institutional and other preconditions for the emergence and diffusion of new technologies. In particular, the studies on national innovation systems argue foremost against neoclassical approaches. Technical innovations are endogenised and it is shown that different national, but also sectoral institutional systems vary according to their quantitative and qualitative innovativeness. Some countries generate innovations more often than others, and the innovations can be incremental or radical. Usually,

Table 2.1 Institutional approaches to technical innovation

	Socio-economic	Politico-economic	Techno-sociological
Main focus	National systems of innovation	Varieties of capitalism	Coordination of large technological systems
Types of innovation	Radical/incremental Frequent/seldom	Radical/incremental Discrete/cumulative	Radical/conservative Incompatible/compatible
Theoretical profile	Endogenisation of technology and innovative capacity	Correspondence of institutional variety and type of innovation	Phase models of non-linear technical development
Understanding of institutional systems	Institutions are heterogeneous elements of constellations	Systems are constellations of complementary institutions	Systems incorporate technological elements
Repercussions of innovations	Convergence of institutions; (rare) changes of techno-economic paradigms	Innovations can influence adaptive institutions	Technological momentum exerts pressure towards institutional adaptation
Theoretical perspective	Alternation of periods of social construction and technological determinism	Co-evolution of institutional and technological development	Actor-mediated interaction of institutional and technical development

socio-economic institutionalism applies a broad and rather inconsistent concept of institutions, which has hampered the theoretical development of this approach.

Politico-economic institutionalism on the other hand strives for a theoretically sound concept of institutions and institutional systems. This approach focuses not only on economic performance, and in this context on technical innovations, but at times also on institutional change. The regulatory function of institutions moves into the centre of attention. Particularly useful has been the stylised distinction of liberal and coordinated market economies. As ideal-types, both exhibit a high degree of internal complementarity of their institutional elements, which accounts for their strong stability. Technical innovations are regarded as important for politico-economic analyses because they influence a country's economic performance. It has been shown that liberal market economies are not superior to coordinated market economies in all aspects. Instead, economies prove their specific capabilities with respect to different types of technical innovations. Liberal market economies are conducive to radical innovations; coordinated market economies promote incremental innovations.

Politico-economic institutionalism further develops this distinction between radical and incremental innovations, which is predominantly used in socio-economic studies. To answer the question of why radical innovations frequently occur in coordinated market economies (contrary to all expectations), the studies further distinguish between discrete and cumulative technologies. The latter can be enhanced step by step once a technological basis has been established. In this

respect, they fit in coordinated market economies, even though they emerge, as far as their fundamental basis is concerned, as radical innovations. Hence, incrementally enhanced radical innovations may also prosper in coordinated economies.

According to this perspective, innovations are not continuously regarded as dependent variables. Technologies may even at first appear as exogenous variables, when it is argued, for instance, that German enterprises face great problems with radical innovations but utilise incremental innovations successfully. Enterprises adapt their strategies to the opportunities and constraints of technology. However, they will also try to shape a technology according to their own strategic orientations. The resulting innovations may exert pressure to change on national institutional systems. Innovations are hence intervening variables. Enterprises use technologies to the extent that they can integrate them with their strategies. The integration takes place via adaptation to technology, but also via the technology's modification and change. As a result, the technological opportunity structure will change, and that, in turn, generates pressure on institutional change.

Institutionally oriented sociological technology studies regard the development and diffusion of innovations mainly as a coordination problem, with (large) technological systems as their preferred subject of research. Similar to politico-economic studies, they predominantly understand institutional systems as rule systems. However, techno-sociological institutionalism usually confines itself to reducing the modes of institutional coordination to the basic types of hierarchy, market and network. Only occasionally do the studies consider mixed types. This leads to similar problems as those confronting socio-economic institutionalism: while socio-economic institutionalism mainly gains a profile demonstrating the weaknesses of neoclassical approaches, techno-sociological institutionalism is particularly attractive where it demonstrates the dubiousness of the notion of a linear development of technology. All in all, institutional theory has only advanced rudimentarily. One promising approach is the so-called actor-centred institutionalism (Werle 1998). It helps to explain technological changes within a relatively stable institutional framework by conceptualizing actor constellations and actor strategies as varying factors of influence on technology (see Schmidt and Werle 1998).

It is remarkable that techno-sociological institutionalism examines not only success or failure of technical innovations, but also the temporal and factual sequence of the innovation process and the solution of ensuing coordination problems. The process is expected to pass several phases which may recur cyclically. The resulting dynamic momentum confronts the embedding institutions with diverging challenges. A given institutional constellation which changes only slowly or not at all may benefit or hamper the process.

The socio-economic, politico-economic and also the techno-sociological analyses usually do not scrutinise the details of technical innovations, but instead use simple descriptive categories such as radical and incremental. This 'black-boxing' – if it is not too undifferentiated – facilitates exploring the general relation or correspondence between institutional constellations and technical innovations. This holds true at least as long as institutional constellations are also characterised

by means of general typologies such as hierarchy, market, network, or coordinated/liberal market economies. The alternative method to providing a more detailed account of institutions and technology has not yet yielded convincing generalizable findings, although the tendency has increased to look in more detail at hybrid or "mixed governance" modes (Weyer 2006; see also Schneider and Bauer 2009).

All three approaches treat innovations primarily as dependent variables, but apparently their development and diffusion is institutionally underdetermined. Many other factors affect innovations, too. Moreover, technology-induced factors may exert pressure on the institutions to change. But the majority of studies adhere to the assumption that institutions are relatively resistant to these pressures.

Should studies in which institutions are used to explain technical innovations not also consider the inverted causal relation? Some studies mention this possibility. The socio-economic concept of a changing techno-economic paradigm, for instance, postulates that revolutionary technological changes abolish an existing institutional regime and establish a new one (Freeman and Perez 1988). From a comparative perspective, it is argued that in countries in which new technologies are less successful than in others, reform processes are targeted at institutions which are particularly relevant for technology policy, which then may enhance the fit of technology and institutions (Giesecke 2000). Similar arguments can be found in politico-economic studies about "institutional adaptiveness" (Casper 2000). Finally, the sociology of technology repeatedly points to the dynamics and momentum of technology, which requires conceding technology's strong impact on society and its institutional structure.

Here, the concept of co-evolution plays an important role. Insofar as relevant studies using this concept are empirically oriented, they use data and ideas of the history of technology. Here the development of technology is conceived of as a process in which periods of "social construction" i.e., organizational and institutional shaping of technology, alternate with periods of "technological determinism" i.e., technology-induced changes of the organizational and institutional environment (Rosenkopf and Tushman 1994).

Particularly in its techno-sociological variant (Rip and Kemp 1998; Geels 2005), the concept of co-evolution is definitely an interesting approach, since it overcomes institutional determinism and suggests a way to explain the fact that innovations occasionally also succeed in a virtually 'incompatible' institutional environment. However, the concept is very broad. It includes not only technological and institutional but also multiple other variables. To further elaborate on the relationship between technological and institutional innovations, case studies should search for interdependencies or interactions between them. The guiding idea is that *technology and institutions change in interactive processes* which are mediated and influenced by individual and collective actors (see Werle 2007). But technological and institutional change is always also affected by other, from this perspective, exogenous factors. A research design focusing on interdependencies and interactions will require systematically relating categories and mechanisms of institutional and technological change to one another and, as a by-product, prove to be generally fruitful for institutional theorizing. It definitely shows a way out of

the impasse of institutional determinism, which is puzzled by cases of successful technical innovations that do not match the institutional environment.

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