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Technological Innovation in Network Industries: Four Building Blocks for a Comparative Framework

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Abstract

Starting with the idea that innovation in network industries is a relatively underdeveloped research theme, the paper suggests and discusses four different perspectives on the study of innovation in and between network industries: economic, entrepreneurial, technological, and political perspectives. The conceptualization of each perspective is discussed and indicators are suggested to facilitate their empirical research. Applying the four perspectives together provides a more definite understanding of the differences and similarities in innovation between network industries.

Keywords

Innovation, network industry, comparative framework

1. Introduction

In recent decades network industries have been reformed and restructured throughout the world.[1] The reforms, which have been studied under different labels, such as deregulation, liberalization and privatization, ended a long period of monopoly regulation. This was no easy task, thanks to the network industries' institutional and technical outlook (Finger, Groenewegen et al., 2005; Green, 2007; Künneke, 2008). In for instance electricity supply "The crucial task in implementing electricity reform is how to provide the necessary conditions for efficient operation and investments in a sector that is characterized by: (i) large sunk costs, (ii) a mixture of competitive and natural monopoly activities, (iii) organised markets with instantaneous physical balance of supply and demand, and (iv) delivery of a non-storable good" (Jamasb and Pollitt, 2005). The reforms were motivated by the need to increase productivity and efficiency in the industries to benefit society at large. Economic theory – in particular mainstream economics – provided arguments for competition- focused reforms and the devices and tools needed to implement them. For a brief historical account of these developments, see (Voss, 2007).

Thus far the scholarly focus has concentrated predominantly on the impact of the reforms on static efficiency, the dominant performance indicators being cost reductions, productivity increase and reduction of costs per unit of product. Less research has been done on the impact of the reforms on innovation and dynamic efficiency (Jamasb and Pollitt, 2005). Nevertheless, the impact of the reforms on innovation is not only an interesting, but also a very relevant research theme. One of the ideas underlying the reforms was that competition would also stimulate and accelerate innovation. Since Schumpeter, innovation and technical progress have been considered essential for longer term survival and economic development (Freeman, 2003). The hope was that the introduction of competition would lead to innovation and a new economic dynamic. The lack of scholarly attention to innovation in network industries is remarkable for at least two reasons.

First, intuitively the differences in innovation dynamics between network industries seem remarkable. Compared to telecommunications, the number and speed of product and process innovations in gas, water, rail and electricity remain laggardly. In telecommunications, innovation completely changed the dominant technology and added new technologies for the remote exchange of words, images and data (Lemstra, 2006). Innovations in rail, gas and electricity had no effect, either on the dominant technology or the industry's organization; they did change components and the management of the technical infrastructure. Nevertheless, the overall impact of innovation on the products and services, prices and the outlook of these industries appear rather modest compared to telecommunications. These differences raise the question of what causes them and what are the differences and similarities between network industries in terms of stimuli and barriers to innovation?

Second, certain innovations in network industries may readily be expected for political reasons. For instance, in gas and electricity there is a political expectation that energy production and supply will be decarbonized to reduce greenhouse gas emissions and climate change. Electricity

[1] In the context of this paper we consider the former utility sectors electricity, gas, water, rail and telecommunication to be network industries.

and heat production and consumption is considered one of the major contributors to the greenhouse gas effect, compelling us to adapt and move to renewable (carbon-neutral) energy resources to cover the ever-increasing energy needs of modern industrial society. In the water supply industry, innovation is expected to ameliorate the problems of scarcity and health. In rail transportation, innovation is required to overcome the capacity problems and increase the safety of passengers and goods. Last but not least, in telecommunications the quest for innovation should handle problems of privacy and cyber crime. In other words, both society and politics entertain rather lofty expectations with respect to innovation in network industries.

It is relevant to conduct systematic analyses and draw comparisons between network industries with respect to the drivers and impacts of innovation. For several reasons, network industries are not commodity markets like pharmaceuticals, food processing, car manufacturing and computers. Network industries are atypical due to their technological infrastructure (Finger, Groenewegen et al., 2005; Jamasb and Pollitt, 2008). Given these specific characteristics, the question is how can innovation in network industries be systematically compared? In this paper we wish to contribute to answering this question by suggesting building blocks for the development of a more comprehensive framework for the analysis and comparison of innovation in network industries. Our analysis is guided by the following research question: *How can we understand similarities and differences between network industries with respect to innovation?*

The paper draws on findings from evolutionary economics, science & technology studies and political science to develop the argument. In particular, we explore innovation in network industries from four different perspectives: economic, management, technological, and political. We believe these four perspectives together are better able to develop a more conclusive understanding of innovation and innovation dynamics in network industries. Drawing on this multidimensionality, the paper explores the following drivers of innovation:

1. Competition and innovation: the literature, in particular economic literature, suggests a relationship between competition and innovation: Competion is considered an incentive to innovation. The third section of the paper explores this assumption in more detail and suggests some additions from an evolutionary perspective.
2. Entrepreneurship and innovation: Schumpeter is generally recognized as the founding father of entrepreneurship, which he viewed as key driver of innovation. Entrepreneurs can make a difference, as we all know from Edison, Siemens, Bill Gates and many other past and present men and woman who started with an idea and ambition and initiated change and development. Room for entrepreneurship therefore seems to be important for innovation. Section 4 of the paper explores this theme.
3. Technology and innovation: Other branches of the economic literature (evolutionary and institutional economics), put forward the idea that sectoral innovation has its own routines, traditions and histories, which materialize in cumulative knowledge and skills. This collective memory can have a powerful intervention in innovation. Section 5 of the paper explores the responsiveness of technology to innovation.
4. Politics and innovation: Political ambitions act as a driver of innovation. This is apparently the case in electricity production and consumption, with climate protection as the guiding principle. But politics has – and should have – a wider role in innovation. Drawing on an evolutionary perspective, section 6 explores the role and position of politics in innovation.

As stated above, the paper considers these four dimensions as drivers of innovation. They can act as building blocks for developing a framework to systematically compare innovation in network industries. We start with a brief note on the dependent variable of the framework – innovation – before going on to consider the four drivers of innovation.

2. Innovation

The modern notion of innovation essentially came to us via the seminal work of Joseph Schumpeter. According to Schumpeter, innovation denotes the introduction of five kinds of new approaches by entrepreneurs: new products, new production processes (technologies), new markets, new organizations, and new inputs (Lambooy, 2005) p1137). Schumpeter basically defined innovation in terms of new combinations of existing resources (Fagerberg, 2006) p 6). Schumpeter viewed innovation as part of a trilogy of change: invention, innovation and diffusion (Schumpeter, 1976). Invention is conceived as the generation of new knowledge and ideas, whereas innovation refers to the transformation of inventions into new products and processes, while diffusion refers to the spread of these products and processes into the economic process. Innovation, therefore, can affect both technical and non-technical phenomena. However, innovation and change of *technology* dominates both the qualitative and quantitative analyses. Analysis of non-technical innovations and the interaction between technical and non-technical change and innovation is relatively underdeveloped, but is on the rise (Geels, 2004; Künneke, 2008).

Scholars have suggested different classifications of technological innovation. The most commonly suggested types are incremental vis-à-vis what is labelled as the "revolutionary," "disruptive," "discontinuous," or "breakthrough" type of innovation (Saviotti, 1996; Sood and Tellis, 2005; Beerepoot and Niels, 2007). Saviotti (1996) makes one of the rare attempts to clarify types of innovation at the conceptual level. In his book, "Technological evolution, variety and the economy", Saviotti suggested a twin-characteristic representation of technologies,[2] according to which a technology may be depicted with the help of two sets of characteristics: technical characteristics - constituting the inner structure of a technology; and service characteristics - describing the service or functionality for its users (see Figure 1). In this way, he suggests, the differences between technologies can be more easily mapped, as technologies differ either in their technical or in their service characteristics, or both. The twin representation helps to distinguish conceptually between incremental and radical innovations. An incremental innovation is conceived as a change at the level or value of technical/service characteristics, whereas a radical innovation is conceptualized as a *qualitatively* different internal structure of a technology as compared to the previous one, meaning the renewal of the whole set of technical/service characteristics.

[2] Arentsen, Dinica and Marquart (2001), amended Saviotti's twin characteristic model by adding a third, "green", characteristic referring to the environmental impact of technology and innovation.

Figure 1: Technical and service characteristics of technologies[3]

$$\begin{matrix} \textit{Technical} & & \textit{Service} \\ \begin{pmatrix} Xi1 \\ Xi2 \\ . \\ . \\ Xin \end{pmatrix} & \Leftrightarrow & \begin{pmatrix} Yi1 \\ Yi2 \\ . \\ . \\ Yin \end{pmatrix} \end{matrix}$$

Saviotti's highly abstract scheme provides a better conceptual understanding of innovation. Innovation can either be an improvement of the technicalities (the inner structure of a technology), or an improvement in the way the technology provides a service (the external structure), or an improvement in both the technical and service characteristics of the technology. Other scholars make a similar distinction in terms of the form and function of technology (Rip and Kemp, 1998). Hybrid-engined automobiles are a clear example of innovation due to a change in technical characteristics that does not affect the service characteristics of the car. Digital photography can be considered an innovation of both the technical and service characteristics of photography. Digital cameras have had a tremendous effect on the position and function of imaging in society.

Analysing and comparing the changes in technical ad service characteristics of the technology in network industries might provide a richer, more direct understanding of innovation than, for instance, counting patents, licenses and publications, as suggested in the mainstream innovation literature (Kleinknecht and Reijen, 1993). In network industries a comparison of technical and non-technical changes at the level of products and processes is important to reveal the innovations that are taking place Künneke (2008). Separate analyses of change in technical and service characteristics might be important. For instance, high speed trains have similar technical and service characteristics to normal trains, but the differences are also quite significant. Compared to normal trains, the engines and the wheel technology, as well as the comfort and time saved by fast trains are quite different. In electricity production, the technical characteristics of wind and photovoltaic (PV) based production technologies are quite different from the fossil fuelled turbines, but the service characteristics (providing electricity-based services) of the production technology has not changed. In section 5 we shall return to the issue of change and innovation in technology.

3. Competition and innovation

"Many policy makers and researchers believe that competition promotes innovation. This belief has widespread consequences. It is the driving force behind numerous important policy changes, ranging from the deregulation of numerous sectors in the OECD economies to many of the economic reforms in Eastern Europe" (Tang, 2006). The reforms in network industries have been initiated with the idea of increasing and improving the economic performance of the industries.

[3] Figure taken from Saviotti, 1996, 64.

The general expectation was that the introduction of competition would enhance the productivity and efficiency, with all the attendant advantages to consumers and society at large. Within this common-sense thinking, competition was considered to be a strong incentive for innovation, too. Innovation was thought to be necessary to keep up with competitors. Introducing competition, therefore, could act as an incentive to innovation. However, a closer look at competition and innovation shows that the impact of the relationship is less conclusive than mainstream economics might suggest (Canton, 2002; Jamasb and Pollitt, 2008). Scholars disagree both on the kind and direction of the impact of competition on innovation (Scherer, 1992).

Scholars do agree, though, on the general idea that innovation is a precondition for economic growth and development. Econometric research relating innovation indicators to growth rates of total productivity is well developed. Baumol (Baumol, 2002) is very explicit about competition and innovation: “Under capitalism, innovative activity – which in other types of economy is fortuitous and optimal – becomes mandatory, a life-and-death matter for the firm”. According to Baumol there is no single, all-encompassing explanation for “the growth miracle of the free market”, but there are certain explanatory mechanisms, innovation being a core one:

- Oligopolistic competition among large high-tech firms, which compete on the basis of innovation (winner-takes-all) instead of price.
- The routinization of R&D in the firm’s regular activities.
- Productive entrepreneurship devoting itself to productive rather than innovative rent seeking.
- The rule of law allowing the enforceability of patents and contracts.
- The selling and trading of technology. The inventor both applies and trades his innovation.

However, these general notions are questioned in the literature. The controversy goes back to Schumpeter, suggesting that innovation does not just occur under conditions of competition (Scherer, 1992). Canton (Canton, 2002) reviewed the theoretical and empirical literature on the impact of competition on innovation. The results of his review are inconclusive: research does not indicate findings in one direction or the other. The impact of competition can be positive, but the literature suggests that it can also be negative or negligible. Moreover, depending on the type of market, competition can result in a trade-off between static and dynamic efficiency. The first type of efficiency stresses short-term costs and cost reduction, whereas the latter type stresses product and process innovations for longer-term continuity of the industry. The optimum situation is when competition pushes both static and dynamic efficiency, but the conditions for such a balanced situation are not specified. Canton finds no clear impact of competition on innovation in the empirical literature. The results are mixed: competition acts as an incentive to innovation, but not automatically, nor by definition (Canton, 2002 p. 14).

Jamasb and Pollitt (2005; 2008) came to similar conclusions after reviewing the literature on the impact of sector reforms in the electricity industry on R&D spending. They note that the literature on reforms in the utility industries on R&D or innovation is very scarce. They extended the review to other industries to get a better picture of the impact of industry reforms on R&D expenditure. They found a decline in R&D expenditure after the introduction of competition. At the same time they found an improvement of R&D productivity, leading them to conclude that this is in line with the overall efficiency improvements in the reformed utility sectors. What is important for our analysis, however, is that they found no conclusive results on the impact of competition on innovation. They traced a tendency towards a trade-off between static and dynamic efficiency in favour of the first. They concluded: “Despite this apparent increase in innovative outputs, a lasting decline in basic R&D and innovation input in basic research may negatively affect development of radical technological innovations in the long run” (p 31).

Recently, the Dutch Scientific Council for Government Policy (WRR, 2008) also pointed to uncertainties in the impact relationship between competition and innovation, which pretty much depends on the type of competition: competition on price or on products. Price competition might increase product differentiation and this will limit price competition. Price competition can also motivate companies to innovate products, but this requires resources and time to explore new products and processes. Strong price competition keeps companies from this time-consuming search, and is one of the reasons why companies are increasingly withdrawing from fundamental research. They simply can no longer afford to invest time and money in fundamental research with uncertain product outcomes and simultaneous exposure to severe price competition.

Competition and innovation, therefore, cannot be considered as being in a one-to-one relation; it more or less depends on the type of market, type of product and type of competition. For our comparative scheme this would mean that competitiveness in network industries alone cannot be considered an incentive for innovation. Competition as driver of innovation, therefore, needs closer specification. Evolutionary economics can act as an inspiration (Nooteboom, 2008).

In evolutionary thinking, openness and diversity are considered crucial conditions for innovation and this in a way forms a bridge to the assumption in mainstream economics that competition is a precondition for innovation. The fundamental differences between mainstream and evolutionary economics relate to valuing and evaluating economic phenomena. The phenomena that mainstream economics considers to be market imperfections are considered to be incentives for innovation and change in the evolutionary perspective: “In the Hayekian/evolutionary view, the stuff out of which ‘market failures’ are made from the perspective of mainstream economics – such as asymmetric information, radical uncertainty, cumulative knowledge, path dependence, lack of equilibrium, and rigidities – are from an evolutionary perspective the stuff from which markets and innovation are made” (Nooteboom, 2008 p. 34). In the evolutionary perspective the market is not and should not be in equilibrium and a platform for optimum allocation under the condition of perfect information. Imperfect information, differences in knowledge and competences are seen as fertile ground for innovation. This does not imply different views on the necessity of competition. On this point Nooteboom concludes that mainstream and evolutionary economics do agree on the necessity of competition, but the argumentation is different. Competitiveness, openness and no barriers to entry give room to innovation, opening up the selection environment that challenges entrepreneurs and allows the emergence of new combinations.

This brief survey permits us to conclude that mainstream indicators for competition, such as market concentration, entry barriers etc., should be complemented by evolutionarily oriented indicators, such as: diversity of knowledge and competencies, degree of openness to new ideas, knowledge and competencies, degree of openness to new innovative entrants, degree of openness to new areas of application (Nooteboom, 2008 b) p. 98).

4. Entrepreneurship and innovation

The notion of entrepreneur originates in Schumpeter's analysis. He considered the entrepreneur to be the core actor in innovation, creative destruction and economic change (Schumpeter, 1934; 1976). To Schumpeter, entrepreneurs were individuals carrying through new combinations that would change an industry or the economy as a whole. He distinguished four roles in this respect: the inventor of the new idea, the innovator commercializing the idea, the capitalist financing the innovation, and the manager integrating the innovation in day-to-day business (Stam, 2008).

Schumpeter drew on Marx when formulating his ideas on entrepreneurship and economic change and development. Marx proposed the idea of technological competition as a force driving economic development. An innovation by a "first mover", he argued, will be imitated by others due to the benefits of the innovation for the first mover. Other firms in the sector will follow and "…'swarm' the industry or sector with the hope of sharing the benefits (…) This "swarming" of imitators implies that the growth of the sector or industry in which the innovation occurs will be quite high for a while" (Fagerberg 2006 p 15). Schumpeter pointed out that the imitators would be better off if they not only imitated, but also tried to improve on the original innovation. Thus, if the imitators turned themselves into innovators too, then the gains of the initial innovation would increase and would make the innovation diffusion a creative process "– in which one important innovation sets the stage for a whole series of subsequent innovations – and not the passive, adaptive process often assumed in much diffusion research" (ibid. 15). According to Schumpeter, the dynamics surrounding the initial and induced innovations would cluster in certain contexts and from there would spread to the rest of the economy.

For the young Schumpeter it was predominantly the individual entrepreneur who initiated innovation. In his later work Schumpeter also stressed the role of the context of innovation. Due to the routinization of innovation activities in laboratories in combination with globalizing markets, Schumpeter believed that the bigger firms with substantial R&D activities and budgets had become the "entrepreneurs" of innovation (Scherer, 1992). Innovation needed a critical mass and resources that basically were present in the bigger firms. Later work on industrial innovation showed that the loci of innovation might differ substantially between sectors and in time. "One of the striking facts about innovation is its variability of time and space" Fagerberg 2006 p 14.

Entrepreneurship means the introduction of new economic activity that changes the market place (Stam, 2008, p 137). Modern entrepreneurship is closely connected to knowledge centres like universities and knowledge-intensive economic sectors, such as telecom, health technology, biotechnology, and pharmaceuticals. Entrepreneurship is especially reflected by the proximity of knowledge centres as spin-offs or in the form of knowledge spillover. Spin-offs contribute to diversity and experimentation in the economy. A successful entrepreneur manages to change the market, quite often starting on a decentralized level of the economy in a certain niche. A good entrepreneurial climate, therefore, might act as an incentive to innovation.

Almost all network industries have been initiated by what we would now call entrepreneurship in the Schumpeterian meaning. Individuals, driven by ambition and ideas, were convinced they could change the world. From an innovation perspective it is relevant to discover who the entrepreneurs of today are in the different network industries and to what extent they are changing the market. Analyzing entrepreneurship in network industries means going beyond counting patents, licences and R&D spending. Instead, the analysis should dig into the history of patents to see who was behind and to find out what drove the inventor and innovator. In this way patents can serve to trace the origins of change and innovation in network industries. Such an analysis should not be too narrowly focused on a specific network industry, but instead should keep an eye on related industries and technologies. The literature points to the significance of so-called indirect knowledge spillovers for innovation (Clarke et al. 2006). Indirect knowledge spillovers come from outside into a certain industry. A clear example is digitization and micronization of technology, which has been taken up and utilized by many industries. The mutual fertilization of these technological developments leap-frogged technology, products and services in for instance, telecommunication, printers and copiers and medical technology (Arentsen, Hofman et al., 2007).

5. Responsiveness of technology

Changeability of technology is how we conceive of responsiveness of technology in the context of this paper. From the perspective of innovation it is relevant to know how changeable technology really is. For instance, railroad transportation is bound to the tracks. Despite the presence of technological alternatives (magnetic track), the changeability of the railway system is rather limited. The same holds for the electricity and gas distribution grids. Despite the presence of alternatives (stand-alone electricity systems and tankers) the changeability of the technology is rather limited in practice. Technology in telecommunication, on the other hand, has turned out to be highly changeable. The responsiveness of technology to change might lead to differences in innovation between industries in general, and network industries in particular. The literature on sociotechnical change suggests at least two reasons for the limited responsiveness of technology in network industries: the notion of a large technical system and the notion of socio-technical regimes, routines and trajectories (Markard and Truffer, 2006).

Network industries can be considered as integrated, large technological systems (Hughes, 1983). According to Hughes, who studied the rise and development of electricity systems in the US, large technical systems are well integrated systems composed of technical, physical and organizational components. The structure between the components developed to serve specific purposes, such as the efficient and reliable production and delivery of electricity, or the delivery of postal services every day of the working week, etc. Such a well-organized, harmoniously functioning, large system cannot be changed easily, because a change in one or more components might affect the system as a whole as well as its well functioning. The modern centralized power station electricity system as we know it today is the prototype of the large technical system suggested by Hughes.

Large technical systems thus have an endogenous tendency towards stability and continuity, rather than dynamics and change. However, the history of several network industries shows that the technology of large technical systems can and indeed did change quite drastically, with telecommunication as the clearest example. The electricity and gas industries provide examples of changes in the system’s components without affecting the overall system. In electricity, renewable-based production technology has been added without affecting the overall functioning of the electricity system; and in the natural gas pipeline system, the gases have diversified (synthetic and biogas). These examples show that large technical systems do permit innovations in the components or, in the case of telecommunication, even the overall system. But in case of a large technical system, innovations are always tied to the dominant technological infrastructure, because system-wide technological alternatives are not realistically available in practice for most network industries. Thus far, only in telecommunications does the incumbent fixed communication network co-exist with two mature, alternative infrastructures for data, image and voice communication. In all other network industries the functioning of the system is still tied to one system-wide, technical infrastructure.

The second cause of technological change inertia in network industries goes back to the core meaning of technology. Rip and Kemp (1998 p 330-337) distinguished four different meanings of technology:

1. Technology as tangible skills and things (configuration that works, hardware, software and orgware);
2. Production technology as transformer of input into output;
3. Technology as a key aspect of the sociocultural/sociotechnical landscape of society;
4. Technology as a symbol and as an ideology.

They have combined the four different meanings in the notion of sociotechnical regime, which is conceptualized as “the rule-set or grammar embedded in a complex of engineering practices, production process technologies, product characteristics, skills and procedures, ways of handling relevant artefacts and persons, ways of defining problems; all of them embedded in institutions and infrastructures” (Rip and Kemp, 1998) p. 338). This notion of a sociotechnical regime draws on an analogy with models of scientific change and development, in particular the Kuhnian model of scientific change (Di Nucci Pearce and Pearce, 1989). Other scholars have suggested similar analogies.

A first example is the idea of Nelson and Winter (1982) on trajectory-bound change of technology in cognitive routines and search heuristics in innovation. The second representative is the notion of a techno-economic paradigm suggested by Perez (1983) and defined as “…a cluster of interrelated technical, organisational and managerial innovations, whose advantages are to be found not only in the new range of products and systems, but most of all in the dynamics of the relative cost structure of all possible inputs to production” (Freeman, 1988, p. 10). A third representative is Dosi’s translation of the analogy in the notion of technological trajectory (Dosi, 1982): “a technological *trajectory* is then defined as the development path of *normal* technology (with analogy with Kuhnian normal science)” (Di Nucci Pears and Pears, 1989 p 116).

The analogy models all share the idea that the changeability of technology is conditioned by the accumulation and irreversibility of knowledge incorporated in the artefacts, professions and skills. The learning experiences incorporated in innovation become part of the collective memory and act as a competence reservoir for subsequent innovative steps. This might lead to path dependency: the path followed during the introduction and early adoption of a technology defines the learning process and furthers development of that technology. If this path needs to be changed, then increasing returns to adoption might become a barrier to change and the technology becomes what is called *locked-in*. If a technology or circumstances indeed need to change, then the lock-in might be an extra hindrance and barrier, but if the technology-in-use is of the desired type, the lock-in can be beneficial. In general the connotation of locked-in technology is negative since it is mentioned mostly in reference to the need to change certain technological paths which are very difficult to change.

Both the notion of a large technological system and the notion of socio-technical regime, routine and trajectory suggest causes for inert and limited technological innovation in network industries. Tracing, analyzing and comparing change in such technologically inert environments requires an adequate conceptualization of technology, both in its technical and its service characteristics (see section 2). The conceptualization should also permit analysis at a sufficient level of disaggregation, to be able to trace the almost invisible changes in the predominantly inert technological environments of network industries. For this purpose we draw on Freeman (1979), who distinguishes between technology as a combination of techniques, conceived of as artefact and knowledge. For him, technological change is new knowledge about a technique and technical change the improvement of a new technique or the diffusion of a new technique. Inspired by this conceptualization we conceptualize technology as a configuration of knowledge, skills and artefacts, as indicated in the figure 2.

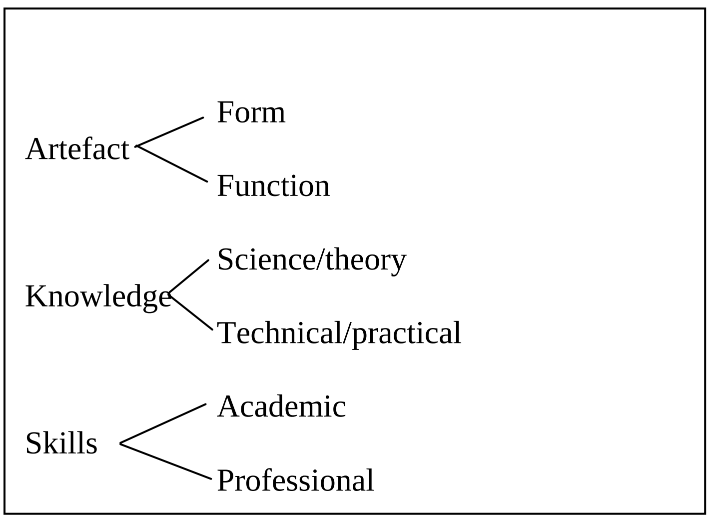

Figure 2 Technology as configuration of artefacts, knowledge and skills

The figure shows three different but related components of technology: artefacts (widely manifested in products, constructions, machinery, etc) and the knowledge and skills necessary to invent, produce and use the artefacts. The artefact can be understood as twin characteristic techniques, as suggested by Saviotti (1996). See also section 2. The suggested difference between technical and service characteristic resembles the notion of form and function of technology (Rip and Kemp 1998). It is essentially in its form and function that an artefact visualizes our understanding of technology.

Technology is also the knowledge necessary to invent, design and produce the technique. Two classes of knowledge are reflected in the artefact: scientific, theoretical or law-like types of knowledge, and technical or practical knowledge. This latter type of knowledge is the engineering knowledge put into the design and production of the artefact. Both science and technical knowledge are grounded in academic disciplines that have evolved through time.

Technology also incorporates the skills necessary to invent, design and produce artefacts. These skills can be of an academic or a professional nature. The first type refers to basic academic skills, such as research methodology and mathematics. The second type refers to the typical technical skills of a profession, such as the professional skills necessary to maintain and repair water systems, electricity systems and gas pipelines. Professional skills are grounded in a particular discipline and are sector-specific. For instance, the construction of artefacts in chemistry requires totally different skills than a mechanical or a civil engineering construction.

Technological change and development in the evolutionary meaning draws heavily on the cumulativeness of knowledge skills and artefacts in socio-technical change (Nelson and Winter, 1982; Boschma, Frenken et al., 2002; Bergh, Faber et al., 2007). The cumulativeness of knowledge skills and artefacts holds in particular for network industries, because of their typical techno-institutional organization as large, integrated technological systems (Finger, Groenewegen et al., 2005; Künneke, 2008). The history of network industries shows their underlying, core evolutionary mechanism: increasing returns to adoption which might lead to path dependency and lock-in, which in turn affects the changeability of technology (responsiveness of technology to innovation and change). From the perspective of innovation it is relevant to analyze the responsiveness in all three components of technology: knowledge, kills and artefacts. The responsiveness of the components might differ within and between network industries. Such detailed and differentiated findings are important not only from an academic point of view, but also from that of society. They hold important information for developing innovation policies for network industries.

6. Politics and innovation

Politics and network industries were and still are closely related. The network industries have long been dominated by monopoly regulation, central planning and state ownership. The political involvement changed after the reforms: no longer direct control and planning, but instead, regulatory incentives and regulatory control. As indicated above, the change of regulation coincided with an intensified political demand for innovation. But how can politics facilitate and support innovation in such a changed regulatory environment? Evolutionary thinking again provides inspiration.

In mainstream thinking it is assumed that politics has a role in facilitating innovation, directly by means of financial support and indirectly by means of a good national system of innovation (Porter, 1990; Lundvall, 1992; Edquist, 2006). Recently scholars have proposed innovation policies grounded in evolution, drawing on core mechanisms of evolutionary change (Saviotti, 1996; Arentsen, Dinica et al., 2001; Boschma, Frenken et al., 2002; Bergh, Faber et al., 2007; Nooteboom, 2008 b). According to these scholars, innovation policy should draw on evolutionary mechanisms of change and development to facilitate innovation effectively. A crucial concept in this respect is diversity.

Diversity refers to variety in human organizations in general and the economic system in particular. This implies that almost no sector, industry or firm is similar, so trying to influence them – by policies, for instance – requires a detailed understanding of the in and outs of economic sectors. The evolutionary argument further states that diversity in search processes, like innovation, increases the chance of achieving a good solution. The idea is simple: the more alternatives there are, and the greater their diversity, the greater the probability that good alternatives will survive.

Nooteboom (2008 b) recently entered a plea for innovation policies that reflect much more strongly how change and innovation actually emerge in real life. His starting point is the core finding in biology that "(…) new forms of life emerge without prior, goal-directed design, in a process that is cumulative, and path- and context dependent…" (p 76). This places learning and uncertainty at the very core of innovation and in this perspective mainstream innovation policy acts as a powerful barrier, according to Nooteboom, because it doesn't facilitate and stimulate learning and it doesn't accept uncertainties in search processes and R&D. In a solid analysis, Nooteboom shows the necessity of changing innovation policy into a facilitator of innovation as a trial-and-error learning process. His analysis culminates in a plea for policy facilitation of a fourfold openness of innovation:
"First, openness to uncertainty in the innovation process, especially in exploration. Second, openness for cooperation with other organisations at an optimal cognitive distance. Third, openness for new innovative entrants. Fourth, openness to new areas of application, in new countries, industries, markets, and organisations." (p. 98).

Nooteboom's plea holds important lessons for innovation policy in general and for innovation policy in network industries in particular. We follow his general idea that innovation policy should facilitate openness in all four dimensions. We briefly indicate how this translates into innovation policy for network industries.

Openness to the uncertainties incorporated in innovation processes might be reflected by fundamental research connected to network industries, especially fundamental research in the knowledge dimension of technology. Fundamental research is very important to develop and improve techniques, products and processes, but at the same time it incorporates great uncertainty about usable outcomes. It is a search and a learning process beyond state-of-the-art knowledge, uncertain but at the same time crucial for an economically feasible, longer-term continuation of industry. Unconditional policy support of fundamental research can therefore be considered a first sign of an open innovation policy, as suggested by Nooteboom.

According to Nooteboom, not only collaboration but also diversity of perspectives in cooperation is important for innovation. He argues for diversity in cooperation with the help of the concept of cognitive distance, reflecting the idea that different types of knowledge have greater potential to produce innovative outcomes. Simply stated, this implies that the probability and quality of innovations increases with the involvement of different types of organizations with different cognitive backgrounds. This is based on the evolutionary mechanism that diversity results in better solutions. "Interaction forces people to try and fit their ideas into the mental frames of the other person (generalization), differences appear and yield a need for adjustment (differentiation), opportunities emerge to try and fit in elements of the other's thought into one's own thinking, in hybrids of thought and practice (reciprocation), which stimulate a novel integration of joint thinking and action" (p. 94). This has important implications for innovation policy, especially for the discursive types of innovation approaches like transition management and innovation platforms currently in use in the Netherlands. Participation in these forums should be as diverse as possible, but it tends to reflect predominantly the current industrial interests. Innovation policy should therefore also address the composition of the innovation networks in network industries.

Openness to new innovative entrants is a third dimension suggested by Nooteboom, relating to openness and competitiveness of markets. In network industries in particular, openness to new entrants can be a problem due to the specificities of the industrial organization and the technical infrastructure, which together form a serious barrier. From EU benchmarking we know, for instance, that energy markets are less open to new entrants than regulation may have assumed (Haase, 2008). In telecommunication, on the other hand, new entrants with small but significant innovations initiated the tremendous transformation that led to the high-tech industry we know today. Innovation policy can support openness to new innovative entrants, for instance by facilitating and supporting spin-offs to help them get into the market, or by allowing experimentation with certain innovations in niches.

The forth dimension is openness to new areas and applications. This kind of openness has two directions: “outside-in” and “inside-out”. The first direction is the most important: openness to knowledge spillovers from outside the industry or sector. Research indicates the importance of these indirect knowledge spillovers to innovation (Clarke et al. 2006). An example of the new areas of application is the gasification of biomass, which connects agriculture, cattle breeding and energy production. Waste water treatment is another candidate for connection with energy production. Waste water residues have an energy content which can be exploited by gasification. Innovation policy can and should facilitate and support these new connections between industries and new areas of application.

Policy in general and innovation policy in particular can act as an incentive to innovation. Besides the political translation of society’s expectations regarding innovation, policies can encourage innovation by facilitating openness and diversity, as Nooteboom suggests.

7. Summary and Conclusion

The paper has suggested and explored building blocks in an analytical, comparative framework for the study of innovation in and between network industries. Research on innovation in network industries has not yet gained great prominence, especially not in relation to recent reforms. Scholars have paid more attention to the reforms themselves and their impact on static efficiency. We commenced our plea for systematic research into innovation in network industries by mentioning two reasons why this type of research is needed. First, there is a remarkable difference in innovation in network industries. Telecommunication deviates sharply from the general pattern of innovation in network industries. Second, politics expresses high expectations in regard to the network industry’ technologies, and these expectations assume quite a high degree of technological innovation.

Due to the specificity of network industries, the analysis of the drivers of and barriers to innovation should go beyond mainstream approaches to innovation. The paper therefore suggests a wider framework, drawing on (evolutionary) economics, science technology studies and political science. The paper has explored four different perspectives on innovation as building blocks in the development of a more systematic, comparative framework, guided by the following question: *How can we understand similarities and differences between network industries with respect to innovation?*

The following table summarizes the four perspectives and suggests indicators to facilitate empirical analysis. Each of the four dimensions highlights certain aspects of innovation. Together they permit a more conclusive analysis of incentives and barriers to innovation in network industries. Learning more about the incentives and barriers is important for societal reasons, but also for a more solid, conclusive academic understanding of the differences in innovation between network industries. Systematic knowledge on the causes of these differences is still rather immature.

Dimension	**Indicators**

Competition	• Market concentration
	• Type of competition
	  o Product versus price
	• Degree of openness to:
	  o Entrepreneurs
	  o New knowledge
	  o New combinations (areas and application)

Entrepreneurship	• Diversity of companies • Age of companies • Number of spinoffs • Direct and indirect knowledge spillovers
Technology	• New artefacts • New knowledge • New skills • New combinations

Politics	• Innovation challenging goals
	• Stimulation and facilitation of openness towards:
	  o New exploration
	  o New cooperation
	  o New exploitation
	    ▪ New companies
	    ▪ New applications

Figure 3 Dimensions and indicators of innovation in network industries

The economic dimension of our scheme has been elaborated with the help of findings from mainstream and evolutionary economics. Our analysis has shown that analyzing the degree and type of competition is related to innovation, but this it needs to be supplemented with an analysis of the openness of markets. The evolutionary argument states that openness of markets to new entrants, new entrepreneurs and new areas and applications is important for innovation. The paper further suggests entrepreneurship as separate theme of analysis. Entrepreneurs incubate innovations, which might grow and develop, ultimately to have transformational impacts on the market and industry. The numbers and the diversity of entrepreneurs therefore might function as early signals of emerging innovations in network industries. The paper then analyzed the responsiveness of technology as a dimension of innovation. Technologies differ in their responsiveness to change, especially technology in large technological systems and technologies embedded in long trajectories. The technology of most network industries is that of a large technological system and it has long development paths. The paper distinguished three components of technology (knowledge, artefacts and skills) differing in their changeability over time. Artefacts are more open to change than knowledge and skills, in particular scientific knowledge. Finally, the paper analyzed a political perspective on innovation with a special focus on facilitating openness in industries. This was discussed with the help of the evolutionary notion of diversity as an important condition for novelty and innovation. Translated to the social world, this means that markets should be open to diversity with innovation policy as facilitator and stimulator when markets lag behind in openness.

The next steps we suggest include the further development of the four perspectives into a comparative framework and application of the framework in a systematic comparison of innovation in network industries. This part of the analysis will probably require collaboration with sector specialists because dealing with innovation along all of the four dimensions suggested here will require a detailed, competent analysis by sector specialists. Those who find this challenge appealing are invited to contact the author.

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