The governance of infrastructures as common pool resources

Paper presented on the fourth Workshop on the Workshop (WOW4), June 2–7, 2009, in Bloomington

Rolf Künneke

Associate Professor   Economics of Infrastructures

Faculty of Technology Policy and Management

Delft University of Technology

The Netherlands

R.W.Kunneke@tudelft.nl

Matthias Finger

Professor, Management of Network Industries

Ecole Polytechnique Fédérale Lausanne,

Switzerland

matthias.finger@epfl.ch

Abstract

This paper argues that infrastructures (including energy, communication, transport, and post services) can be perceived as common pool resources providing essential services to society. We investigate the features of infrastructures that can be interpreted as common pool resources. Related to four essential functions (system management, capacity management, interconnection and interoperability) we typify common pool resource problems in infrastructures. Since infrastructures are evolving into ever lager, more complex and international systems, the governance of CPR problems seems to shift from vertically integrated firms under strict governmental control towards a distributed market oriented governance. The institutional and technological fragmentation of infrastructures on one hand, and the globalization of the infrastructure networks and business on the other hand, demand new approaches to govern these vital sectors. Interpreting infrastructures as common pool resources provides insights into a ‘third way’ of regulation based on local initiatives and third sector involvement.

1. Introduction and problem statement

The notion of Common Pool Resources (CPR) *'refers to a natural or man-made resource system that is sufficiently large as to make it costly (but not impossible) to exclude potential beneficiaries from obtaining benefits from its use'* (Ostrom, 1990, p.30). Traditionally this notion is used in relation to natural resource systems, like forests, lakes, or river basins[1]. Common Pool resources are associated to very peculiar governance problems. There are significant problems associated to 'crowding effects' and 'overuse' of CPR's in conjunction with insufficient incentives to invest in the system in order to guarantee its sustainability[2]. Hence, one of the focal points of the governance of CPR's is the regulation of access and a fair distribution of costs and benefits between the users. The dominant focus of common pool resource research is on the governance of socio-ecological systems.

Ostrom claims that similar common pool resource problems can also be recognized in man-made resource systems like for instance irrigation canals, bridges, parking garages, or even mainframe computers (Ostrom, 1990, p. 30). However, comparably little attention is paid to the governance of these kinds of socio technical systems in CPR literature.[3] We aim to contribute to this field of research and especially with respect to infrastructures. Increasingly there are problems related to 'crowding effects' or 'overuse' like for instance traffic congestion in public road systems, or physical bottlenecks in electricity and gas networks. These large scale socio-technical systems seem to be

[1] Refer for instance to the Digital Library of the Commons, The Trustees of Indiana University, 2009
[2] Hardin, 1968 was a pioneer in this field of research based on this analysis of the tragedy of the commons.

confronted with similar problems as compared to socio-ecological systems, for instance with respect to poor investment incentives in order to guarantee the system sustainability, and the regulation of access to prevent the excessive appropriation of goods or services.

This paper explores the significance of common pool resource problems in infrastructures as socio-technical systems, and how they are resolved. The following issues are addressed: What are the features of infrastructures as common pool resources? (section 2); what are typical common pool resource problems related to infrastructures? (section 3); what are typical modes of organization to deal with CPR problems in infrastructures? (section 4); what new insights can possibly be gained by interpreting infrastructures as common pool resources? (section 5).

---

[3] Refer for instance to De Bruijne and Kars, 2007; Frischmann, 2005a, b

2. Infrastructures as common pool resources

In this paper, infrastructures are perceived as complex socio-technical systems in which technological, economic, political, and social features strongly interact with each other (Perez, 2002, Van de Poel, 2003, Kroes et al., 2006, Geels and Schot, 2007). The physical nature of infrastructures is determined by networks that connect various nodes and links. As a consequence, system complementarities create necessities for the coordination of activities. For instance, the delivery of electricity depends among others on the coordination between production units, the transport and distribution of power, and the transformation to a suitable voltage level. These coordination needs, which will be specified more in detail in the next section, highly determine the features of infrastructures as common pool resources. Complementarities cause a strong mutual interrelation between the activities of different users of the network. Entering a public road system has direct implications for the other users if the road is close to its capacity limits, since travelling time increases. The transmission of electricity through the network cannot be technically controlled, but just follows the way of least electrical resistance imposing mutual restrictions to its users. This results in so called loop flows of electric power through parts of the network that are economically not involved in a transaction.

Infrastructures can be perceived as non excludable resources, for at least three reasons. First, infrastructures might be spread through a huge geographical area with difficult to monitor access points, like for instance public road systems. Second, even if the access could be technically monitored, there might be politically motivated universal service obligations, since infrastructures provide essential services like drinking water, energy or means of communication. Third, once the users have entered the network, it might be difficult or even impossible to precisely determine the services they appropriate from the network. Certain services cannot be individually monitored like for instance the use of many public roads, certain services that are necessary to technically balance the electricity network (i.e. load balancing, voltage control, and reactive power), or the quality control of drinking water. These are open access services from which each individual user takes benefit at the expense of others; i.e., there is rivalry in the consumption. Because of the systemic nature of these services it is difficult or even impossible to strictly assign them to individual users. By using the electricity network, there is an inherent need for load management, voltage control and the provision of reactive power. However, different patterns of use and different technical characteristics of the user applications cause different needs for these services. Individual users extract these services from the system without reflecting on its technical or economic sustainability.

It has to be stressed that these appropriation problems do not occur for all services provided by infrastructures. Actually the appropriation of some services can be monitored very well and attributed to specific consumers. Examples include the consumption of cubic meters drinking water, kilowatt hours electric power or kilometers of transportation services in railway systems. But this is the exception rather the rule. The point is that significant infrastructure services fit the category of common pool resource services and therefore its allocation is related to attribution problems.

Another typical feature of common pool resources are the dubious and diffused property rights and decision rights with respect to the resource system and the appropriation of its services. Traditionally infrastructures were vertically integrated firms which were able to control all relevant aspects of the resource system. This is the case of 'closed access CPR'[4]. However, as a consequence of the institutional restructuring (i.e. liberalization), this vertical integration slowly eroded into an unbundled value chain with hybrid modes of organization and diffuse property rights structures.[5] Nonetheless, in a technical sense the system remains a network with a strong degree of complementarity and consequently fundamental coordination needs. Under liberalized market conditions the coordination needs are now to be performed by a multitude of actors with different interests and responsibilities. This development contributed to the emergence of CPR problems.

Infrastructures show a tendency towards an increasing size and complexity.[6] Many infrastructures started as local initiatives, but evolved into regional, national and international operating utilities. At least some infrastructures (like energy, transport, and electronic communication) reached a scale and degree of complexity that is hardly to be monitored form one central authority or point, as it often was done in the past. The technical scope of these infrastructures generally crosses national boundaries and hence creates increasingly a need for international cooperation. Technical coordination is even more difficult under these circumstances, because appropriate governance structures need

[4] Ciriacy-Wantrup and Bishop, 1975, cited from Ostrom, 1990, p. 222, note 23
[5] An illustrative example is provided by Künneke and Fens, 2007
[6] With respect to information network see for instance Noam, 1992, who provides a very illustrative example of the different stages of network development.

to be defined under different legal systems and national systems of regulation. This contributes to the evolution of diffused property rights as mentioned in the previous paragraph.

Likewise in socio-ecological systems, infrastructures are typically used for multiple purposes. Drinking water might be used for cooking food or washing a car. Power is necessary for private consumption needs as well facilitating industrial production processes. Rail tracks can be used for the transport of goods or persons. Depending on these purposes, different demands are made on infrastructure services, and there are different needs for long term investments and system development. Related to this dynamic perspective, it has also to be taken into consideration that over time the use of resource systems changes. New services are added or others are getting less significant. The copper cables of the telephone network are initially designed to enable voice communication. Nowadays they are mostly used for data communication with very different technical needs and system services.[7] In a common pool resource system these processes of change are accompanied by the need to redefine governance structures. New appropriation problems might arise, there are new investment needs, and new stakeholders can get involved in the exploitation of common pool resources.

In conclusion it can be stated that infrastructures can be perceived as common pool resources since they fit major features of this notion: a non-excludable resource system, appropriation problems related to rivalry in consumption of essential services,

[7] The same holds for socio-ecological systems which also need to adjust to changing societal needs. For example some river basins might be traditionally used for fishing and the provision of drinking water,

coordination needs deriving from system complementarities, diffuse property rights and decision rights with respect to the resource system, and multiple purpose services contributing to disperse and conflicting stakeholder interests. In the next section we will further specify the nature of common pool resource problems in infrastructures.

3. Common pool resource problems in infrastructures

Common pool resource problems are typically manifested by the 'overuse' of certain goods or services beyond a sustainable consumption level, or 'crowding effects' indicating that the individual acquisition of services takes more effort than expected. We relate CPR problems to four essential functions that have to be performed in all infrastructures in order to safeguard a satisfactory technical functioning (Finger et al., 2005, p.240-241), i.e. system management, capacity management, interconnection, and interoperability. These four functions define different categories of system services that are freely accessible but can be appropriated by individual users, and hence causing CPR problems.

System management pertains to the question of how the overall system (e.g., the flow between the various nodes and links) is being managed and how the quality of service is safeguarded. Typically system management consists of short-term activities related to the actual coordination of activities within the network. This can be a very critical activity in liberalized infrastructures in which network activities are unbundled from commercial

whereas nowadays recreation or marine transport have come more significant.

business. Indeed, the so unbundled actors pursue their own strategic objectives (e.g., conflictual objectives between the rail infrastructure operator and the rail transport operator), yet the system can only function if the operations of the involved actors are somewhat aligned. With growing fragmentation of the technical systems because of unbundling, outsourcing, and the like, there is therefore a growing need to coordinate all operations and actors involved. The most obvious example here is slot allocation, which is a new function that becomes necessary in both air and rail transport after the separation of infrastructure and transport. Obviously slot allocation is an important mode of organization to avoid congestion and secure the safety of the system and thus resolves a common pool resource problem.

Capacity management is another important system function. Networks are scarce resources because the capacity of nodes and links is limited. Capacity management deals with the allocation of this scarce network capacity to certain users or appliances. Different levels of capacity management can be distinguished[8]. On a strategic level network access and scope are important issues. Which actors are in general allowed to use infrastructures and what is the desirable scope of service? On a tactical level the actual access to networks needs to be facilitated by suitable regulations, for instance with respect to tariffs and technical quality standards. The operational level addresses real-time capacity management issues, which are related to the logistical aspects of directing the flows of services and goods through the various nodes and links. The physical limitations of networks pose high demands on the balancing of demand and supply of infrastructure services, which are often not storable. The electricity sector is a very illustrative example in this respect. Since electricity storage is only possible on a very limited scale and at very high costs, power production and consumption has to be balanced nearly instantaneously. There are very sophisticated models of load balancing developed for this sector in order to mitigate or avoid the overuse of the systems which results into major failures as blackouts.

Interconnection deals with the physical linkages of different networks that perform similar or complementary tasks (e.g., Economides, 1996). As such, interconnection is closely related to the technical system's boundaries. Typical examples include the interconnection of different telecom networks, railroad tracks or electricity systems. Interconnection occurs sometimes even beyond the limited boundaries of specific infrastructures. A similar development emerged in the transportation sector through the introduction of standardized containers. This technology allows for very fast and efficient intermodal traffic between roads, shipping, or air traffic. Containers allow for a much better interconnection between these different infrastructures. A failure to realize a sufficient degree of interconnection might cause congestion and an unsustainable use of the system. In addition, even severe economic problems arise as a consequence of an insufficient scale of operation and hence diseconomies of system. Typical symptoms include lower system reliability, less security of supply, and high transaction costs.

Interoperability is realized if mutual interactions between network elements are enabled in order to facilitate systems' complementarity. For example, in the railroad sector, the specification of the tracks needs to be aligned with the needs of the locomotives. In the

---

[8] Ten Heuvelhof et al., 2003

aviation sector, airlines rely on specific navigation systems that guide planes to their destination without accidents. Interoperability ensures that the elements of the network are combinable. In other words, interoperability defines the technical and institutional conditions under which infrastructure networks can be utilized. Examples of modes of organization that resolve problems of interoperability are technical norms & standards and regulatory conditions for access. In this sense, interoperability is also of strategic importance. It determines the conditions of use as well as the rules for entry and exit to this specific facility. In many public infrastructures open access is required as a public service obligation. Sometimes, certain technical standards are defined in a way to establish barriers to entry for disturbing competitors.

It appears that in infrastructures four essential functions can be identified that are closely related to common pool resource problems. Since these functions are vital for the technical functioning of infrastructures, there need to be some modes of organization to support or enable them. The following section provides a brief overview how these modes of organization evolved through the past decades.

4. The governance of CPR problems in infrastructures

The four above identified functions are all essential, to various degrees, for the different infrastructures to properly operate. As said above, each of these essential functions requires proper institutional arrangements so that the infrastructure will ultimately function as a system. It is this systemic nature of the infrastructures which we have assimilated to a common pool resource problem. The intellectual background of such considerations pertains to the co-evolution between technology and institutions[9]. Indeed, infrastructures typically developed from integrated technologies, governed by a national monopoly, towards ever more distributed technologies, governed by a combination of market, government, and the third sector, something commonly called governance. One can distinguish between three stages (or three configurations) of this co-evolution from integrated to distributed technologies and from government to governance. These three stages or configurations define different types of sectorial organization (or different degrees of market), namely monopolistic competition, access competition, and network competition. In each of these three configurations, the four essential functions play different roles and will be governed differently so as to ensure the technical system's integrity and the common pool resource problems:

- In monopolistic competition (competition for the market), which is typical in water distribution and sewerage, all the four essential functions are still integrated into one single operator, but the responsibility for all these functions is transferred to a third party, generally a private actor.

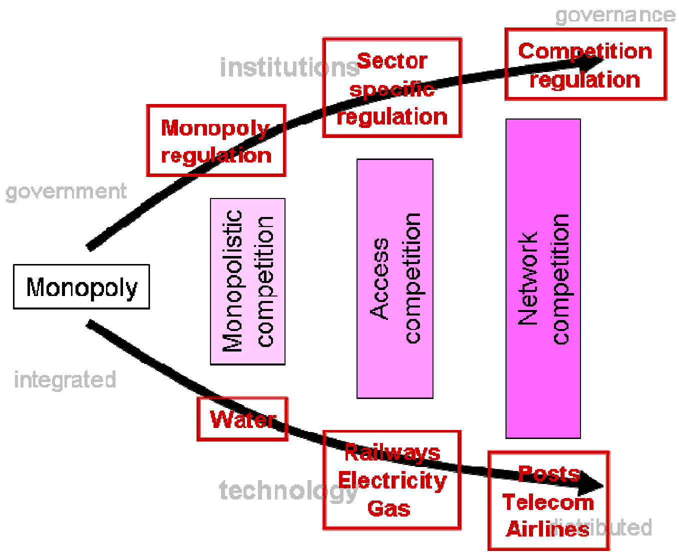
- In access competition, which is typical in electricity, gas and railways, the ultimate responsibilities for interconnection, interoperability, capacity management and system management are transferred to the government, generally in the form of a sector specific regulator.

- In network competition, which is typical for telecommunications, postal services and air transport, interoperability, capacity management and system management generally remain with the operators, while the responsibility for interconnection lies with the government, generally in the form a competition regulator.

The following figure 1 summarizes this evolution.

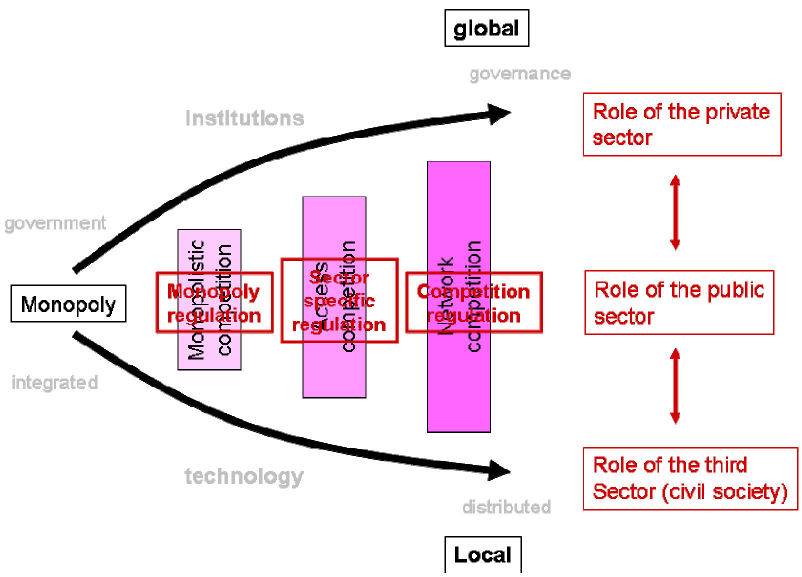
[9] Von Tunzelmann, 2003; Nelson, 1995; Tushman and Rosenkopf, 1992

Figure 1: Different configurations between institutions and technology in infrastructures



However, as these infrastructures evolve from integrated national monopolies to distributed technological networks, the role and responsibilities of government for ensuring the system's integrity and thus for addressing the common pool resource problems is gradually reduced and replaced by new forms of governance, involving simultaneously the public, the private and the third sector. This evolution parallels the evolution from national to simultaneously global *and* local infrastructure systems. The following figure 2 presents this evolution.

Figure 2: Changing roles and responsibilities in infrastructure regulation



It is here where the common pool resource literature, and especially its focus on third sector / civil society involvement is particularly relevant. Indeed, common pool resource theories, especially Ostrom, stress the fact that there are other solutions than bringing the common pool resource under a central authority, namely by way of self governance or "governance by network" (as opposed to governance by government ordering or by the market). However, Ostrom also admits that there must ultimately be some underlying governance rules, which point to the possibility that infrastructures, once simultaneously distributed and systemic beyond the national level combine self-governance, government ordering and markets.

Interestingly, we can observe what we call "infrastructure commons" in the third most advanced stage or configuration of infrastructure evolution, namely in telecommunications and postal services in the form of local FTTH (Fiber to the home) common networks, community wifi networks, [10] or self-help city-couriers, for example. All over the world local communities contribute to the development of these networks, often on a non profit basis even in regions where 'official' providers are absent because of an expected low profitability. While these local networks are still interconnected to the overall infrastructure system, they allow for a certain decoupling of these local systems from the overall systems. Similar evolutions can be found in distributed electricity and distributed public transport. Infrastructure commons therefore point to new and interesting ways to manage common pool resource problems in large socio-technical systems, in particular ways where civil society self-governance can play a much more active role.

5. New insights from the interpretation of infrastructures as CPR?

In the previous sections we demonstrated that infrastructures can be perceived as common pool resources. There are distinctive CPR problems related to four essential functions. The modes of organization that are required to mitigate these problems are getting increasingly complex as a consequence of institutional and technological developments. This brings us to the last question to be addressed in this paper: What new insights can possibly be gained by interpreting infrastructures as common pool resources?

[10] Lemstra and Hayes, 2009

In this stage of research the answers to this question are speculative and they certainly need further elaboration. The governance of infrastructures is becoming increasingly complex, both from an institutional and technological perspective, as demonstrated in section 4. Traditional approaches of strict governmental regulation or even public ownership are not any more possible under the conditions of sector re-regulation and technological innovation resulting in an even stronger fragmentation of the system. But also the stronger reliance on competition and private sector involvement in liberalized infrastructures does not lead to the expected results. The common pool characteristics of infrastructures are per definition related to fundamental market failures and market imperfections. Hence we are confronted with a fundamental problem in which neither governmental intervention nor the markets are able to cope with the newly arising common pool resource problems in these essential infrastructure sectors.

CPR literature might provide insights into a ‘third way’ of regulating infrastructures next to (or even beyond) markets and governmental involvement. Interesting directions to be explored would be the involvement of local initiatives or communities in the governance of infrastructures. As a consequence of technological innovations, at least some of the four essential technical functions might be monitored and controlled on a subsystem level by locally embedded actors or authorities. What is needed is a much more detailed understanding of the conditions under which individual actors or local communities are prepared to contribute to the sustainability of essential functions of infrastructures. This is not only an issue of ‘getting the institutions right’. Our short overview on the historical development of infrastructures in section 4 clearly demonstrates that we have to account for the co-evolution between institutions and technologies. Hence, certain CPR problems might be mitigated predominantly by technological means, others by regulation, private or third sector governance, or a combination of both.

It appears that the resolution of CPR problems in infrastructures is an issue in which the co-evolution between institutions and technology has to be taken into consideration. This is a novel facet which is not sufficiently recognized in the traditional CPR literature.[11] When doing so, we observe that technological evolution – in particular the growing role of the ICTs (Information and Communication Technologies) – allows for ever more decentralized and distributed technological solution in all infrastructures, which in turn leads to new forms of governance of these vey infrastructures involving no longer exclusively government, but also the private and the third sectors.

6. Conclusion

In this paper we explore the significance of common pool resource problems in infrastructures. We investigate the features of infrastructures that can be interpreted as common pool resources. Related to four essential functions (system management, capacity management, interconnection and interoperability) we typify common pool resource problems in infrastructures. We argue that the mitigation of these CPR problems is typically an issue of institutional and technological change. Since infrastructures are evolving into ever larger, more complex and global systems, the governance of CPR problems seems to shift from vertically integrated firms under strict governmental control towards a form of governance which increasingly involves the market, but which also has the potential to ever more involve the third sector. Indeed, the institutional and technological fragmentation of infrastructures on one hand and the globalization of the infrastructure networks and business on the other hand, demand new approaches to govern these vital sectors. Interpreting infrastructures as common pool resources provides insights into a 'third way' of governance beyond government regulation based on local initiatives and private sector involvement, sometimes even without strong economic objectives. Further research is necessary into the decentralized governance of common pool resources in infrastructures.

[11] Refer for instance to Finger et al., 2005; Künneke, 2008

References

Ciriacy-Wantrup, S.V., Bishop, R.C. (1975) "Common Property" as a Concept in Natural Resource Policy. Natural Resources Journal 15, 713-723.

De Bruijne, M.L.C., Kars, M. (2007) CPR theory as a guideline for capacity management in infrastructures? The cases of electricity and mobile telephony, Eleventh International Research Symposium on Public Management (IRSPM XI), Potsdam University, Germany, April 2-4, 2007, Potsdam.

Economides, N. (1996) The Economics of Networks. International Journal of Industrial Organization 14, 673-699.

Finger, M., Groenewegen, J.P.M., Künneke, R.W. (2005) The Quest for Coherence Between Technology and Institutions in Infrastructures. Journal of Network Industries 6, 227-259.

Frischmann, B.M. (2005a) An Economic Theory of Infrastructure and Commons Management. Minnesota Law Review 89, 917-1030.

Frischmann, B.M. (2005b) Infrastructure Commons. Michigan State Law Review 89, 121-136.

Geels, F.W., Schot, J. (2007) Typology of Sociotechnical Transition Pathways. Research Policy 36, 399-417.

Hardin, G. (1968) The Tragedy of the Commons. Science 162, 1243-1248.

Kroes, P., Franssen, M., van de Poel, I., Ottens, M. (2006) Treating Socio-technical Systems as Engineering Systems: Some Conceptual Problems. Systems Research and Behavioral Science 23, 803-814.

Künneke, R.W. (2008) Institutional Reform and Technological Practice: The Case of Electricity. Industrial and Corporate Change 17, 233-265.

Künneke, R.W., Fens, T. (2007) Ownership Unbundling in Electricity Distribution: The case of The Netherlands. Energy Policy 35, 1920-1930.

Lemstra, W., Hayes, V. (2009) License-exempt: Wi-Fi complement to 3G. Telematics and Informatics 26, 227-239.

Nelson, R.R. (1995) Co-evolution of Industry Structure, Technology and Supporting Institutions, and the Making of Comparative Advantage. International Journal of the Economics of Business 2, 171 - 184.

Noam, E.M. (1992) A Theory for the Instability of Public Telecommunication Systems, in: Antonelli, C. (Ed.), The Economics of Information Networks. North Holland, Amsterdam, pp. 107-127.

Ostrom, E. (1990) Governing the Commons: The Evolution of Institutions for Collective Action. Cambridge University Press, Cambridge.

Perez, C. (2002) Technological Revolutions and Financial Capital: The Dynamics of Bubbles and Golden Ages. Edward Elgar, Cheltenham, UK.

Ten Heuvelhof, E.F., Kuit, M., Stout, H.D., Bauer, J. (2003) Capacity Management in Infrastructures: Lessons from the Dutch Experience, in: Ten Heuvelhof, E.F.K., M.; Stout, H.D.; Bauer, J (Ed.), Critical Infrastructures: State of the Art in research and Application. Kluwer Academics, London, pp. 165-180.

The Trustees of Indiana University (2009) Digital Library of the Commons, http://dlc.dlib.indiana.edu/about.html

Tushman, M.L., Rosenkopf, L. (1992) Organizational Determinants of Technological Change: Towards a Sociology of Technological Evolution. Research in Organizational Behavior 14, 311-347.

Van de Poel, I. (2003) The transformation of technological regimes. Research Policy 32, 49-68.

Von Tunzelmann, N. (2003) Historical Coevolution of Governance and Technology in the Industrial Revolutions. Structural Change and Economic Dynamics 14, 365-384.